# SPACE WEATHER: ADVANCING RESEARCH, MONITORING, AND FORECASTING CAPABILITIES

## JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT
SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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C O N T E N T S

**October 23, 2019**

# SPACE WEATHER: ADVANCING RESEARCH, MONITORING, AND FORECASTING CAPABILITIES

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**WEDNESDAY, OCTOBER 23, 2019**

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT,
JOINT WITH THE SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
*Washington, D.C.*

The Subcommittees met, pursuant to notice, at 2:42 p.m., in room 2318 of the Rayburn House Office Building, Hon. Lizzie Fletcher [Chairwoman of the Subcommittee on Environment] presiding.

**COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**
**SUBCOMMITTEE ON ENVIRONMENT**
**SUBCOMMITTEE ON SPACE AND AERONAUTICS**
**U.S. HOUSE OF REPRESENTATIVES**

# HEARING CHARTER

***Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities***

Wednesday, October 23, 2019
2:00 p.m.
2318 Rayburn House Office Building

## PURPOSE

This hearing will provide an opportunity to discuss the current state of space weather research and federal efforts to monitor and predict space weather events with a specific focus on identifying what is needed to improve our space weather forecasting prediction capabilities. It will also examine how collaboration among federal, academic, and commercial sectors can best support advances in the field of space weather and space weather forecasting and prediction capabilities among other relevant issues.

## WITNESSES

- **Mr. Bill Murtagh**, Program Coordinator, National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC)
- **Dr. Nicola Fox**, Heliophysics Division Director, National Aeronautics and Space Administration (NASA)
- **Dr. Conrad C. Lautenbacher, Jr., VADM USN (ret.)**, CEO of GeoOptics, Inc, and former Under-Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator (2001-2008)

## OVERARCHING QUESTIONS

- What are the top research, modeling, and operational questions that need to be addressed to improve our space weather prediction and forecasting capabilities?
- What is the current state of space weather research being conducted at federal agencies, and in the broader space weather community?
- What are the research-to-operations and operations-to-research processes in the field of space weather, and how can these processes be improved?
- What is the role of the commercial sector in the field of space weather?
- What is the status of our current observational infrastructure, and how do we sustain and enhance these observations?

**BACKGROUND**

***What is Space Weather?***

The term "space weather" describes an array of naturally occurring solar phenomena that can impact activities on Earth. Common space weather phenomena include solar flares, solar winds, coronal mass ejections (CMEs), and solar radiation storms. The movement of energized particles from the Sun into the Earth's magnetosphere can cause geomagnetic storms that can be disruptive to space-based and ground-based technologies.

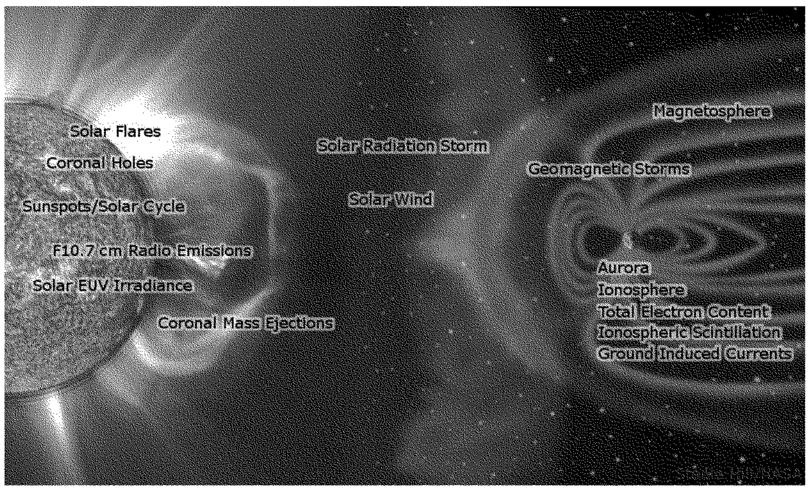

Figure 1. https://www.swpc.noaa.gov/phenomena

***Societal and Economic Impacts of Space Weather Events***

Though severe space weather events may occur once or twice every few decades more routine variabilities in the space environment can impact assets in space, in the near-earth environment, and on the ground on a more regular basis. A 2017 NOAA-sponsored report determined the societal and economic impacts to operations in four sectors. [1]

- Impacts to electric power grids: reactive power consumption, transformer heating, improper operations of protective relaying equipment, generator tripping, loss of precision timing.
- Impacts to satellites: loss of altitude, link disruption, anomalies, cumulative dosage.
- Impacts to global navigation satellite systems (GNSS): ranging errors, loss of lock.

[1] https://www.weather.gov/media/news/SpaceWeatherEconomicImpactsReportOct-2017.pdf

- Impacts to aviation: communication and navigation degradation, avionic upsets, effective dose.

The report also found that "scientific research on space weather contributes knowledge that is essential for designing and engineering robust and safeguarded systems," and found that proactive investments to prevent impacts are significantly low compared to the costs of recovering from an event. Additionally, the report noted that industry plays an important information-sharing role, further justifying the inter-disciplinary approach articulated in the Space Weather Action Plan.

In addition to the broader impacts of space weather on our space and ground-based infrastructure, space weather poses risks to human spaceflight operations due to the damaging particles emitted during geomagnetic storms. Astronauts on the International Space Station (ISS) exhibit evidence of radiation damage to cells and DNA from constant exposure to highly charged particles of solar and galactic origins.[2] Beyond low-earth orbit, however, the space radiation environment is far more severe, and poses more serious risks to astronauts.

***Interagency Coordination on Space Weather Activities***

The Office of Science and Technology Policy (OSTP) established the Space Weather Operations, Research, and Mitigation (SWORM) Task Force in November 2014. The SWORM Task Force is comprised of 13 federal agencies including NASA and NOAA, and has a goal of developing a path forward to improve space weather preparedness.[3] In 2015, the SWORM released its first National Space Weather Strategy and Space Weather Action Plan (SWAP) which established priorities and strategic goals to strengthen interagency partnerships and collaboration with the larger space weather community. In March 2019, the SWORM released an updated National Space Weather Strategy and SWAP that supersedes the 2015 versions.[4] The 2019 SWAP and Strategy identified three high-level actions to enhance preparedness for space weather events: 1) Enhance the protection of National Security, Homeland Security, and Commercial Assets and Operations against the Effects of Space Weather; 2) Develop and Disseminate Accurate and Timely Space Weather Characterizations and Forecasts; and 3) Establish Plans and Procedures for Responding to and Recovering from Space Weather Events.

The current decadal survey for solar and space physics (or Heliophysics) is the 2013 *Solar and Space Physics: A Science for a Technical Society.*[5] The report directs its recommendations primarily to NASA and NSF, but it also recommends actions by other agencies, particularly NOAA. The report makes recommendations specific to space weather as a set of Applications recommendations, separate from its Science recommendations, to enable effective space weather and climatology capabilities. Summaries of those recommendations are listed in the table below.

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[2] National Research Council. 2008. *Managing Space Radiation Risk in the New Era of Space Exploration.* The National Academies Press, Washington, D.C.
[3] https://www.sworm.gov/index.html
[4] National Science and Technology Council. March 2019. *National Space Weather Strategy and Action Plan.* https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[5] National Research Council. 2013. Solar and Space Physics: A Science for a Technological Society. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

A mid-decade assessment of the progress implementing the decadal survey is currently underway and is expected to be released by the end of 2019.[6]

| Heliophysics Decadal *Applications* Recommendations | |
|---|---|
| *Program* | *Notes from Decadal Recommendation* |
| 1. Recharter the National Space Weather Program | As part of a plan to develop and coordinate a comprehensive program in space weather and climatology, the survey committee recommends that the National Space Weather Program be rechartered under the auspices of the National Science and Technology Council. With the active participation of the Office of Science and Technology Policy and the Office of Management and Budget, the program should build on current agency efforts, leverage the new capabilities and knowledge that will arise from implementation of the programs recommended in this report, and develop additional capabilities, on the ground and in space, that are specifically tailored to space weather monitoring and prediction. |
| 2. Work in a Multiagency Partnership to Achieve Continuity of Solar and Solar Wind Observations | The survey committee recommends that NASA, NOAA, and the Department of Defense work in partnership to plan for continuity of solar and solar wind observations beyond the lifetimes of ACE, SOHO, STEREO, and SDO. |

***Space Weather Forecasting***

NOAA's Space Weather Prediction Center (SWPC), part of the National Centers of Environmental Prediction under the National Weather Service (NWS), is the primary source of civilian warnings and forecasts for space weather. SWPC is jointly operated with the U.S. Air Force and conducts research on solar-terrestrial physics, develops techniques for forecasting solar and geophysical disturbances, and provides real-time monitoring and forecasting of solar and geophysical events.

NOAA contracted a report, finalized in 2019, to identify customer needs and requirements for space weather products and services.[7] The study assessed "the variety of uses and needs for SWPC space weather information across five sectors: (1) electric power, (2) satellites, (3) global navigation satellite systems (GNSS), (4) aviation, and (5)" emergency management. It showed that all five sectors utilized SWPC products, but that there were improvements that could be made to improve accessibility and usability of the products.

***Current Observational Infrastructure***

NOAA SWPC uses data from a suite of observing platforms to provide space weather forecasts. These include NOAA assets as well as observations from other federal partners. NOAA has multiple instruments for collecting space weather data on its Geostationary Operational Environmental Satellites (GOES) system. The Deep Space Climate Observatory (DSCOVR) satellite, launched in February 2015, is a partnership between NOAA, NASA, and the U.S. Air

[6] http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_174910
[7] Abt Associates. "Customer Needs and Requirements for Space Weather Products and Services. March 29, 2019. Accessed here: https://www.swpc.noaa.gov/news/customer-needs-requirements-space-weather

Force, and was developed to succeed the NASA Advanced Composition Explorer (ACE) satellite to provide real-time solar wind observations from the L1 orbit.[8 9] NOAA supports space based observational assets with ground-based tracking systems.

NASA's Heliophysics Division currently operates 26 spacecraft in diverse locations, several of which are making observations related to space weather:

- Advanced Composition Explorer (ACE), launched in 1997, measures the particles in the solar wind, which can originate not only from the Sun, but also from interplanetary or interstellar (galactic) space. ACE can provide an advance warning of about one hour for geomagnetic storms on Earth.
- Solar and Terrestrial Relations Observatory (STEREO), launched in 2006, provides stereoscopic measurements to study the Sun and coronal mass ejections (CMEs).
- Solar Dynamics Observatory (SDO), launched in 2010, is contributing to our understanding the fundamental nature of the Sun's magnetic field, as well as how it generates solar wind.
- Global-scale Observations of the Limb and Disk (GOLD), launched in 2018, measures the temperature and composition of neutral gases in the Earth's thermosphere, part of an effort to understand the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics and can stymie terrestrial communications.
- Parker Solar Probe, launched in 2019, is making approaches closer to the Sun's surface than any previous spacecraft in order to study the flow of energy and the heating of the solar corona and to understand the acceleration of the solar wind.
- Ionospheric Connection Explorer (ICON), launched in 2019, will study the boundary region where the uppermost layers of the Earth's atmosphere interacts with the charged particles of the solar wind.

The Heliophysics Division also has a suborbital program that supports CubeSat, balloon, and sounding rocket investigations in space weather and other areas of Heliosphere research. In additional to space-based observations, ground-based assets also provide critical data for space weather forecasts. The data from the United States Geological Survey (USGS) Geomagnetism Program monitors the Earth's magnetic field to provide continuous records of magnetic field variations is used by NOAA to characterize geomagnetic storms.[10] NSF's Global Oscillations Network Group (GONG) also provides ground based solar observations.[11]

***International Partnerships***

NASA partners with other space agencies in a number of areas relevant to space weather. The most significant example in the current fleet of missions relevant to space weather is the Solar and Heliophysics Observatory (SOHO), a mission to study the internal structure of the Sun and the solar wind. SOHO, launched in December 1995 and still operating today, is a partnership between NASA and the European Space Agency (ESA). The coronagraph images captured by SOHO's Large Angle Spectrometer Coronagraph (LASCO) instrument are utilized by SWPC to

[8] Lagrangian point 1, or L1, is approximately 1 million miles away from Earth.
[9] On June 27, 2019 the DSCOVR satellite was placed in Safehold mode and is not returning any space weather data in this mode, with NOAA relying on data from the ACE satellite to inform their operational space weather activities. The ACE satellite is currently the only source of real-time solar wind observations from L1.
[10] https://www.usgs.gov/natural-hazards/geomagnetism
[11] https://gong.nso.edu/

characterize the solar corona and is a vital tool for forecasting the impact of CMEs and the effects of solar winds on the Earth.[12]

NASA is also a partner in the upcoming ESA-led Solar Orbiter mission, set to launch in February 2020. The Solar Orbiter mission will travel close to the Sun to take both *in situ* and remote sensing measurements to aid in scientists' understanding of how the inner heliosphere works and how it is affected by solar surface activity.

***Future Observational Infrastructure***

To ensure consistent observations of space weather phenomena, NOAA and NASA are developing assets to continue space weather data collection in the near-term. NOAA is working with the Naval Research Laboratory (NRL) to develop a compact coronagraph (CCOR) to be deployed on the GOES-U satellite that is currently set for a 2024 launch. The CCOR will image the solar corona and observe CMEs to help determine their size, mass, and speed. This information can help space weather forecasters provide forecasts, warnings, and watches for space weather events over a day in advance.[13] The CCOR will succeed the SOHO/LASCO satellite for CME imagery. There is currently no backup to SOHO/LASCO for CME imagery. NOAA is also in conversation with NASA to launch a space weather follow-on L1(SWFO-L1) as a hosted payload on NASA's upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission. On October 3, 2019 NOAA released a Broad Agency Announcement (BAA)[14] for the submission of white papers to conduct studies of instrument and mission concepts to support needs for space weather data collection.

NASA recently announced the initiation of the Interstellar Mapping and Acceleration Probe (IMAP) mission, a decadal recommended mission. IMAP is slated to launch 2024 and will study the interaction of the heliosphere with the interstellar medium and the particles streaming to Earth from the edge of interstellar space. The decadal survey also recommended a large mission -- the Geospace Dynamics Constellation reference mission --to study the ionosphere-thermosphere-mesosphere system of the Earth's atmosphere in an integrated fashion, focusing on how Earth's atmosphere absorbs solar wind energy, and NASA has supported preliminary studies on the mission.

***Current Space Weather Research and Findings***

NASA's Heliophysics Division, in the Science Mission Directorate (SMD), studies the fundamental nature of the Sun and its interactions with Earth and other bodies of the Solar System. The solar wind—a constant outflow of particles from the Sun as well as interplanetary and interstellar space—and solar activity like coronal mass ejections (CMEs) and solar flares influence the space environment and can interact with the Earth's atmosphere and magnetic field.

NASA recently initiated the Space Weather Science Application (SWxSA) project, a dedicated effort to transition space weather tools, models, data, and knowledge from research to operational environments.[15] In addition, NASA and its Goddard Space Flight Center leads the

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[12] https://www.swpc.noaa.gov/products/lasco-coronagraph
[13] https://www.nesdis.noaa.gov/OPPA/ccor.php
[14] https://www.fbo.gov/index?s=opportunity&mode=form&id=e73adc85a721fb3425c506a6dec0aef8&tab=core&_cview=1
[15] Congress appropriated $15 million to dedicated space weather research in FY 2018 and FY 2019.

Community Coordinated Modeling Center (CCMC), a multi-agency partnership that provides access to modern space science simulations to the international community and CCMC supports space weather forecasters through transitioning modern space research models to space weather operations, evaluating models as an unbiased agent, and providing forecasting tools.

***Academic Role***

Fundamental scientific questions relevant to space weather remain unanswered. Apart from the continued need for observations of solar phenomena, gaps exist in our understanding of the foundational physics that *drive* these solar phenomena. Greater support of federally funded research to study the physical processes behind space weather will help improve the utilization of our observational data. Enhanced scientific understanding coupled with robust observations are vital to improving space weather forecasting capabilities.

***Commercial Interest and Role***

The decadal survey highlights a "maturing commercial space weather enterprise."[16] Similarly, the 2019 National Space Weather Strategy and Action Plan calls for "the coordination and collaboration within and across the Federal Government, as well as engagement with the commercial sector, academia and like-minded nations."[17] The American Commercial Space Weather Association (ACSWA), founded in 2011, represents 19 member companies that offer "support ranging from algorithmic development services to numerical modeling and simulation including the magnetosphere, ionosphere and lower atmosphere."[18]

To date, the commercial entities have mainly advised the federal government on critical space weather issues, but a number of private sector actors are increasingly interested in building space weather observational infrastructure and data capabilities to enhance United States' and global preparedness. The SWPC also works with commercial service providers and the international community to acquire and share information needed to carry out its role in serving the nation with space weather products and services.[19]

**Legislation**

On March 26 2019, Senator Gary Peters introduced S. 881 – *Space Weather Research and Forecasting Act*. It passed out of the Senate Committee on Commerce, Science, and Transportation on April 3, 2019. The bill's stated purpose is to "*improve understanding and forecasting of space weather events, and for other purposes.*" The bill delineates responsibilities for space weather observations and forecasting, research and technology, and data among the various federal agencies, and also directs the Office of Science and Technology Policy, along with the interagency National Science and Technology Council, to coordinate research and preparedness efforts across the federal space weather enterprise.

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[16] National Research Council. 2013. *Solar and Space Physics: A Science for a Technological Society*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.
[17] National Science and Technology Council. March 2019. *National Space Weather Strategy and Action Plan*. https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[18] http://www.acswa.us/
[19] National Research Council. 2013. *Solar and Space Physics: A Science for a Technological Society*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

Chairwoman FLETCHER. This hearing will come to order.

Without objection, the Chair is authorized to declare a recess at any time.

Good afternoon, and welcome to today's joint Subcommittee hearing on advancing our Nation's space weather activities. I'm happy to be here with my colleague, Space and Aeronautics Subcommittee Chairwoman Horn, to discuss the important topic of space weather.

The term space weather may not be familiar to everyone, but we are aware of some of its more benign examples, such as the northern lights. Space weather describes naturally occurring disturbances in space that are primarily driven by the sun. These variations in the space environment can negatively impact technology in space such as satellites for weather and GPS, pose health risks to our astronauts, and also affect critical ground-based systems such as electric grids. Despite knowing the potential for these significant impacts, our ability to forecast space weather events with significant notice is limited at best.

Given our society's dependence on many technologies that could be impacted by space weather events, it's critically important that we understand both the physical processes that drive these phenomena, and how we can forecast them earlier to allow adequate protection of critical assets. For this we need to invest in scientific research and sustained observations.

NOAA (National Oceanic and Atmospheric Administration) is responsible for the civilian forecasting through the National Weather Service's Space Weather Prediction Center, SWPC. The forecasters and scientists at SWPC collect data and observations from their own network of satellites and work in close partnership with other Federal agencies including NASA (National Aeronautics and Space Administration), who we have here today, the U.S. Air Force, the National Science Foundation (NSF), and the United States Geological Survey (USGS), among others.

Assets in space provide key data necessary for accurate and timely space weather forecasts. Disruptions in this data due to malfunctions, as we are currently seeing with NOAA's Deep Space Climate Observatory, or DSCOVR, satellite, without a long-term redundancy plan puts our critical infrastructure in space and on the ground at risk.

A recent study contracted by NOAA on customer needs for space weather products and services found that space weather disturbances can impact major sectors of society, including aviation, electric power, navigational satellites, and emergency management. It highlighted the utility and importance of NOAA's space weather products to protecting their infrastructure from damage, but also made clear that they can be further improved to allow for greater accessibility and usability.

Improvements in our understanding of space weather will come through robust collaboration between the Federal Government and partners in both the commercial and academic sectors. Though we only have witnesses representing the government and commercial sectors today due to unforeseen circumstances, I would like to stress the important role that the research community plays in shaping these conversations. This is especially true when it comes to understanding the outstanding science questions in this field. It is critical that we continue to foster these partnerships between the government, academia, and commercial sectors. Indeed, it's something that I often remark when I'm at home this Committee in particular does so well.

I'm looking forward to today's discussion about the current state of our space weather activities, from fundamental research to forecasting, and receiving feedback on how Congress can support improvements to our forecasting capabilities.

[The prepared statement of Chairwoman Fletcher follows:]

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I am looking forward to today's discussion about the current state of our space weather activities, from fundamental research to forecasting, and receiving feedback on how Congress can support improvements to our forecasting capabilities.

Thank you.

Chairwoman FLETCHER. I would now like to recognize Mr. Marshall for an opening statement.

Mr. MARSHALL. Thank you, Chairwoman Fletcher, for holding this important hearing today on the topic of space weather. I also want to thank our three witnesses for being here this afternoon and sharing their expertise on this important topic.

Space weather is a term many people have not often heard of. The term refers to the interaction of solar activity with technology and life on Earth, as well as in orbit. This is by no means a new phenomenon, as we have records of solar activity going back more than 150 years. However, our need to forecast this phenomenon has become more critical as our utilization of space-based technology has increased.

When I consider the importance of space weather research to Kansans, I think about the potential negative impacts solar activity can have on our farmers and ranchers. The agriculture sector is usually among the first of industry who adapt new and innovative technologies to improve their operations.

Kansas farmers in particular have been at the forefront of adapting precision agricultural practices. Precision agriculture refers to the use of technologies such as GPS and unmanned aerial vehicles to make decisions related to planting crops and implementing conservation practices. The use of these technologies helps our farmers make better informed decisions about the timing and location of planting crops in order to minimize irrigation and the use of fertilizer and pesticides. I've seen firsthand the improvements in productivity and crop yields for our farmers and ranchers who utilize these techniques. None of these would be possible without the use of GPS and satellite imagery, which are vulnerable to solar weather incidents.

Accurate weather forecasting is another concern for our farmers. Knowing precisely when to plant crops can help significantly reduce input costs for farmers, which in turn reduces costs for consumers. An especially severe space weather event has the potential to damage our orbiting weather satellites, which in turn would significantly reduce the accuracy of our weather forecasts needed to help our farmers make informed decisions.

A final area of concern for rural Kansans is the potential impacts a geomagnetic storm could have on our electrical grid. We have a basic understanding of the potential disruptions a severe event can make on our power grid, resulting in blackouts which would affect hospitals, schools, businesses, and our farmers. What we still need is a more advanced knowledge of how to prevent or mitigate the damages a space-weather-caused blackout could have on critical infrastructure.

I look forward to hearing from our witnesses on how we can ensure rural Kansas and all Americans are prepared for these events. Thank you, Chairwoman Fletcher, and I yield back.

[The prepared statement of Mr. Marshall follows:]

Thank you, Chairwoman Fletcher, for holding this important hearing today on the topic of space weather. I also want to thank our witnesses for being here this afternoon and sharing their expertise on this important topic.

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I look forward to hearing from our witnesses on how we can ensure rural Kansans and all Americans are prepared for these events. Thank you, Chairwoman Fletcher, I yield back.

Chairwoman FLETCHER. Thank you. I'll now recognize the Chair of the Subcommittee on Space and Aeronautics, Ms. Horn, for an opening statement.

Chairwoman HORN. Thank you, Chairwoman Fletcher.

Good afternoon, and welcome to our witnesses. I look forward to your testimony today. And I am so pleased to be working with Chairwoman Fletcher and the Ranking Members on these two Subcommittees on this important hearing about space weather and advancing research, monitoring, and forecasting capabilities. This is an incredibly timely hearing, because it allows us to talk about the connection between what we do in space and our lives every day here on Earth.

Our activities in space not only advance and enable scientific discovery and exploration, but also on the Earth banking, telemedicine, natural resource management, and so much more.

The orbiting spacecraft above—weather, communications, GPS, and Earth-observing systems—are a critical part of our national infrastructure. Solar phenomena or space weather such as solar flares, solar wind, geomagnetic storms of energized charged particles, however, can disrupt ground and space-based technologies and infrastructure. Space weather can affect everything from electrical power systems, satellites, aircraft, space operations, including human spaceflight operations, and other ground and space-based systems. The list is long. In short, severe space weather events pose a significant threat to our infrastructure, and in turn, to our economy, our national security, and our lives here on Earth.

Currently, NASA's heliospheric research satellites and a NOAA-NASA-Air Force operational satellite collect observations used in space weather modeling and predictions. NASA's Advanced Composition Explorer and the joint European Space Agency NASA SOHO mission launched over 20 years ago, along with other NASA spacecraft such as STEREO and the Solar Dynamics Observatory. They provide critical information in forecasting solar eruptions and their movement through the heliosphere. However, these systems are aging, and we will have gaps in space weather data once they reach the end of their operating lifespans. We must develop the next generation systems for space weather observations.

As a first step, however, we need to understand at a national level what space weather observations and systems are needed. Simply put, we need a strategy because we are only at the early stages of our ability to predict and forecast space weather. Improving our current capabilities will require a strategy and investments in basic research, observations, models, and the ability to transition research and models into operational use.

The National Academies' 2013 Solar and Space Physics Decadal Survey stated, "Achievement of critical continuity of key space environmental parameters, their utilization in advanced models, and application to operations constitute a major endeavor that will require unprecedented cooperation among agencies in the areas in which each has specific expertise and unique capabilities."

Making advances in space weather will require a coordinated effort among researchers, operational institutions, government, academic, commercial, and international entities. The role and perspectives of academia are essential in this effort. And while we were unable to include the academic perspective today due to unforeseen circumstances, as Chairwoman Fletcher noted, it's important to recognize the importance of academia in advancing space weather capabilities.

Madam Chair, the Nation's efforts to address the threats of space weather demonstrate the ways in which our investments in NASA and basic research benefit our society. In the case of space weather, these investments are integral in ensuring the safety and operations of our critical infrastructure on the ground and in space. I look forward to hearing from our witnesses on what is needed to advance our Nation's understanding and ability to monitor, predict, and forecast space weather. Thank you and I yield back.

[The prepared statement of Chairwoman Horn follows:]

Good afternoon, and welcome to our witnesses. I look forward to your testimony. I'm pleased be working with you, Madame Chair, on this important joint hearing on "Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities."

This is a timely hearing, because it allows us to talk about the connection between what we do in space and our everyday lives on Earth. Our activities in space enable not only scientific discovery and exploration, but also banking, telemedicine, natural resource management, and so much more. The orbiting spacecraft above-the weather, communications, GPS, and Earth observing systems-are a critical part of our national infrastructure.

Solar phenomena-or space weather- such as solar flares, the solar wind, and geomagnetic storms of energized charged particles, however, can disrupt our ground and space-based technologies and infrastructure.

Space weather can affect everything from electrical power systems, satellites, aircraft, and spacecraft operations (including human spaceflight operations), and other ground and spacebased systems. In short, severe space weather events pose significant threats to our infrastructure, and in turn, to our economy, national security, and society.

Currently, NASA heliospheric research satellites and a NOAA-NASA-Air Force operational satellite collect observations used in space weather modeling and prediction. NASA's Advanced Composition Explorer and the joint European Space Agency-NASA SOHO mission launched over 20 years ago, along with other NASA spacecraft such as STEREO and the Solar Dynamics Observatory, provide critical information in forecasting solar eruptions and their movement through the heliosphere.

However, those systems are aging, and we will have gaps in space weather data once they reach the end of their operating lifetimes. We must develop the next generation systems for space weather observations.

As a first step, however, we need to understand at a national level what space weather observations and systems are needed; we need a strategy. Because we are only at the early stages of our ability to predict and forecast space weather. Improving our current capabilities will require a strategy and investments in basic research, observations, models, and the ability to transition research and models into operational use.

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Madame Chair, the nation's efforts to address the threats of space weather demonstrate the ways in which our investments in NASA and basic research benefit our society. In the case of space weather, these investments are integral in ensuring the safety and operations of our critical infrastructure on the ground and in space.

I look forward to hearing from our witnesses on what is needed to advance our nation's understanding and our ability to monitor, predict, and forecast space weather. Thank you and I yield back.

Chairwoman FLETCHER. Thank you. I'd now like to recognize the Ranking Member for the Subcommittee on Space and Aeronautics, Mr. Babin, for an opening statement.

Mr. BABIN. Thank you, Madam Chair. I really appreciate it. And thank you witnesses for being here. Thank you for holding this hearing, absolutely. Thank you, Chairwoman.

Today's hearing is on a growing topic of national concern, even if it is not an issue most of our constituents might immediately identify with. Space weather, commonly defined, refers to variations in the space environment between the Earth and the sun due to solar activity. This is an ongoing phenomenon which typically has minimal consequences. However, it can have widespread effects such as interfering with GPS signals and disruptions to our electrical grid during severe events. We have had to be more mindful of the effects of space weather as we have increased our use of satellites for communication and remote sensing in our daily lives.

Space weather is an issue of importance across the Federal Government. Agencies such as NASA and NOAA within our Committee's jurisdiction play an important role in increasing our knowledge and better monitoring space weather. However, it's important to acknowledge space weather as a national security issue. Our military has a variety of assets in orbit around Earth which could be potentially harmed by electromagnetic interference and are dependent upon satellites built by NASA and operated by NOAA for timely and accurate information.

Both the Obama and Trump Administrations have acknowledged the need for better coordination of space weather-related activities across the Federal Government by developing and updating a Space Weather Strategy and an Action Plan. This plan covers topics about how Federal agencies should identify and protect infrastructure from acute space weather events which agencies should lead mitigation and research activities.

Our Nation's infrastructure is not all that is threatened by space weather events. I proudly represent the Johnson Space Center, the home to NASA's Astronaut Corps. These are the astronauts who currently work on the International Space Station (ISS) more than 200 miles above the Earth's surface and will one day serve on missions to the Moon and Mars. While we have developed techniques and technology to reduce the threats posed by increased radiation exposure due to a severe solar event, we have much more work to do to mitigate these hazards to our astronauts.

As the Ranking Member of the Space and Aeronautics Subcommittee, I've supported efforts to spur the commercialization of low-Earth orbit by private sector companies. These new entrants into the space economy have a vested interest in protecting their assets. However, they also offer an opportunity to provide data and resources to our Federal agencies as we seek to improve our space weather efforts.

As this Committee potentially considers legislation relating to space weather monitoring and research, we must be certain that whatever legislation that we mark up is not a top-down legislative mandate and ensures a role for the commercial sector. The *Weather Research and Forecasting Innovation Act*, which was passed by this Committee and signed into law 2 years ago, serves as a template for how we could accomplish this. The *Weather Act* took steps to integrate commercial weather data into NOAA's forecast models, and a similar model should guide us when developing space weather legislation.

I want to thank our witnesses for taking the time to attend today's hearing and sharing your valuable experiences and expertise on this very important topic. And I look forward to a productive conversation on how we best move forward.

And with that, Madam Chair, I yield back.

[The prepared statement of Mr. Babin follows:]

Thank you for holding this hearing, Chairwoman Fletcher.

Today's hearing is on a growing topic of national concern, even if it is not an issue most of our constituents might immediately identify.

Space weather, commonly defined, refers to variations in the space environment between Earth and the sun due to solar activity. This is an ongoing phenomenon which typically has minimal consequences. However, it can have widespread effects such as interfering with GPS signals and disruptions to our electrical grid during severe events. We have had to be more mindful of the effects of space weather as we have increased our use of satellites for communication and remote sensing in our daily lives.

Space weather is an issue of importance across the federal government. Agencies such as NASA and NOAA within our committee's jurisdiction play an important role in increasing our knowledge and better monitoring space weather. However, it is important to acknowledge space weather as a national security issue. Our military has a variety of assets in orbit around Earth which could be potentially harmed by electromagnetic interference and are dependent on satellites built by NASA and operated by NOAA for timely and accurate information.

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Our nation's infrastructure is not all that is threatened by space weather events. I proudly represent Johnson Space Center, the home to NASA's astronaut corps. These are the astronauts who currently work on the International Space Station more than 200 miles above the Earth's surface and will one day serve on missions to the Moon and Mars.

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As the ranking member of the space and aeronautics subcommittee, I've supported efforts to spur the commercialization of low Earth orbit by private sector companies. These new entrants into the space economy have a vested interest in protecting their assets. However, they also offer an opportunity to provide data and resources to our federal agencies as we seek to improve our space weather efforts.

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I want to thank our witnesses for taking time to attend today's hearing and sharing your experience and expertise on this important topic. I look forward to a productive conversation on how best we move forward.

Thank you and I yield back.

Chairwoman FLETCHER. Thank you, Mr. Babin. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Thank you, Chair Fletcher.

I am pleased that the committee is holding this hearing to examine crucial knowledge gaps that the space weather community is working hard to address. I look forward to continuing the discussion begun last Congress on how the federal government can leverage our research, monitoring, and forecasting capabilities to protect communities and limit costs to our economy. It is my hope to move bipartisan space weather legislation through the Committee this Congress that has support from the full space weather community.

Though not as publicly prominent as the day-to-day weather generated by Earth's atmosphere and oceans, space weather also can disrupt lives and damage critical infrastructure. Solar events such as solar flares, solar wind, coronal mass ejections, and solar radiation storms send electromagnetic radiation towards Earth's atmosphere which can disrupt GPS function, radio and satellite communications, and our electric grid. Severe space weather events occur about once a decade, though more mild variability is routine.

The need for research on space weather is clear, as fundamental scientific questions remain unanswered. Sustained space weather observations and monitoring are equally important. It is commonly said that space weather prediction is around 50 years behind terrestrial weather predictions; however, innovations such as Cubesats may be able to help advance space weather research and operations.

I look forward to hearing from our expert panel to get an update on the state of space weather R&D, and to explore how Congress can facilitate high-level goal-setting and coordination among federal agencies, the commercial sector, and academia. I am delighted to see representatives from NOAA and NASA, the two lead agencies that carry out research, collect data, and generate space weather predictions, as well as a distinguished panelist from the commercial sector. Though our panelist from the academic sector was unable to make it due to unexpected circumstances, the contributions of the academic community are greatly appreciated. All three sectors do critical work conducting the research, making the observations, analyzing the data,improving the models, and bolstering the preparedness of technologies, industry sectors, and communities affected by space weather.

As I've said before, it is important for Congress to continue the forward momentum of what was set in motion by the National Space Weather Strategy and the National Space Weather Action Plan in 2015. The persistent threat posed by space weather to our economy, which is more and more reliant on space- and ground-based infrastructure makes clear the need for additional space weather research and collaboration. Now is the time to put forth a legislative framework that can guide and successfully leverage the ongoing work on this critical issue.

Thank you and I yield back.

Chairwoman FLETCHER. At this time I would like to introduce our witnesses. Mr. Bill Murtagh is the Program Coordinator for the NOAA Space Weather Prediction Center in Boulder, Colorado. In this position, he coordinates preparation and response with emergency managers, industry, and government entities in the U.S. and around the world. Previously, he worked at the Office of Science and Technology Policy as the Assistant Director for the Space

Weather, Energy, and Environment Division where he oversaw the development and implementation of the National Space Weather Strategy and Action Plan. Before this, he spent 23 years in the Air Force working as a weather forecaster.

Next, we have Dr. Nicola Fox, the Heliophysics Division Director in the Science Mission Directorate at NASA. Before that, Dr. Fox was Chief Scientist for Heliophysics at the Applied Physics Lab at the Johns Hopkins University where she was the Project Scientist for NASA's Parker Solar Probe, the first mission ever sent to a star. She previously was Deputy Project Scientist for the Van Allen Probes and the Scientist for the International Solar-Terrestrial Physics program. She received her Ph.D. in space and atmospheric physics from Imperial College London.

Finally, we have retired Navy Vice Admiral Conrad C. Lautenbacher, Jr. Admiral Lautenbacher is the CEO and Director of GeoOptics, a private company that collects and sells actionable Earth systems data to improve prediction and forecasting of weather and climate. He served as the eighth Administrator of NOAA during the George W. Bush Administration where he spearheaded the first-ever Earth Observation Summit. Before NOAA, Admiral Lautenbacher founded a management consulting business, worked in nonprofits, and spent 40 years in operational command and staff positions in the Navy. He received his Ph.D. from Harvard University in applied mathematics.

For our witnesses, thank you for your written testimony, which will be included in the record of the hearing. You will each have 5 minutes for your oral testimony because your written testimony is already included. And when you've completed your spoken testimony, we will begin with questions from the Members. Each Member will have 5 minutes to ask questions of the panel.

We will start with opening statements, and we'll start first with you, Mr. Murtagh.

## TESTIMONY OF MR. BILL MURTAGH, PROGRAM COORDINATOR, NOAA'S SPACE WEATHER PREDICTION CENTER

Mr. MURTAGH. Good afternoon, Chairs Fletcher and Horn, Ranking Members Babin and Marshall, and Members of the Committee. I am Bill Murtagh, the Program Coordinator for NOAA's Space Weather Prediction Center, or SWPC, in Boulder, Colorado.

NOAA is the official source of U.S. Government for civilian space weather forecast warnings and alerts to the public, industry, and government agencies. We work closely with the U.S. Air Force, who is responsible for all DOD (Department of Defense) and related national security needs for space weather information. We work with NASA and other Federal agencies, as well as private industry, academia, and international partners, to ensure access to data and analysis that support our 24/7 mission to deliver products and services that protect our society and our economy from space weather events.

These events could drastically affect our electric power grid, telecommunications, our GPS-dependent technologies, astronauts in space exploration, and of course aviation.

Critical to our mission operations are observations, forecasts and warnings, science, and partnerships. I'll briefly highlight each one of these. NOAA uses an array of space and ground-based observations, employing specialized instruments to support our space weather forecast operations and related research. NOAA operates at three viewpoints to acquire the space-based observations necessary to meet SWPC's operational requirements. In Deep Space at the Lagrange Point One (L1), which is located 1 million miles from Earth, we observe the solar wind; at geostationary orbit for key observations of solar flares, x-rays, and energetic particle radiation; and low-Earth orbit for measurements of the ionosphere. NOAA also leverages additional data from NASA and European satellites. And we're in the process of developing the Space Weather Follow-On program, which will provide mission continuity and augment capabilities at the L1 point and in geostationary orbit.

Ground-based data are also important to SWPC operations. In particular, magnetic field observations provided by the USGS, which are critical to our geomagnetic storm warning processes, radio and solar observations provided by the U.S. Air Force and solar and magnetic field labs from the NSF.

Once a solar eruption occurs, forecasters feed these observations into computer models to determine the likely effects of solar events on Earth. These models help forecasters estimate when the effects will begin, how long they will last, and how severe the event will be.

Similar to the categories we use to classify hurricanes or tornadoes, there are space weather scales for communicating the severity of space weather storms. These scales address radio blackouts from solar flares, solar radiation storms due to the sun-emitted energetic particles, and geomagnetic storms from coronal mass ejected plasma and magnetic fields called coronal mass ejections. The scales list possible impacts for each level of storming and indicate how often these events might happen. NOAA's space weather alerts and warnings are employed by Federal agencies and users across many sectors to aid in national preparedness in response to space weather.

NOAA is also advancing our research to operations processes. This includes a new program, the Earth Prediction Innovation Center or EPIC. EPIC will use partnerships with academia, the private sector, and relevant agencies to test and validate new capabilities and transition these capabilities from research to operations, thereby improving our existing forecast and warning capabilities.

NOAA is also exploring with NASA the potential for a space weather testbed to further accelerate the transfer of research to operations and operations to research. Strong public-private partnerships are essential to maintain and approve the observing networks, conduct research, create forecast models, and supply the services necessary to support our national security and our economic prosperity. NOAA is committed to working toward the growth of the private sector as our national infrastructure and technological base becomes more sensitive to the impacts of space weather, thus demanding more improved space weather services. NOAA will continue to explore partnerships with the commercial and academic community as we work to maintain and improve our operational capabilities.

In closing, NOAA appreciates the ongoing support we have received from Congress for our critically important space weather program. We will continue to work with other Federal agencies, the private sector in this effort to develop and strengthen our activities in space weather research and forecasting, and I look forward to answering your questions.

[The prepared statement of Mr. Murtagh follows:]

**WRITTEN STATEMENT BY**
**WILLIAM MURTAGH**
**NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION**
**U.S. DEPARTMENT OF COMMERCE**

**ON**
**SPACE WEATHER: ADVANCING RESEARCH, MONITORING, AND FORECASTING CAPABILITIES**

**COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**
**SUBCOMMITTEE ON ENVIRONMENT**
**AND**
**SUBCOMMITTEE ON SPACE AND AERONAUTICS**
**U.S. HOUSE OF REPRESENTATIVES**
**OCTOBER 23, 2019**

## Introduction & NOAA's Role

Good morning Chairs Fletcher and Horn, Ranking Members Marshall and Babin, and Members of the Committee. My name is Bill Murtagh and I am the Program Coordinator for the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) in the Department of Commerce. Thank you for the opportunity to testify at this hearing about space weather. NOAA is the U.S. Government's official source of civilian space weather forecasts, warnings, and alerts to the general public, industry, and government agencies. NOAA works closely with our partners in the U.S. Air Force (USAF) 557th Weather Wing, who are responsible for all Department of Defense (DOD) and related national security needs for space weather information.

Through the SWPC, NOAA's mission is to deliver space weather products and services that protect our society and economy from space weather events that could wreak havoc on our Nation's electrical grid, telecommunications, GPS-dependent technologies, astronauts and space exploration, and aviation.

SWPC operates 24 hours a day providing observations/situational awareness, forecasts, and warnings of space weather storms with advance notice ranging from hours to days. In addition to the DOD, SWPC efforts are closely integrated with other agencies, including the Department of Homeland Security, National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and the U.S. Geological Survey (USGS), as well as commercial service providers, private industry, and academia. SWPC also works with international partners to ensure access to essential data and analyses that support our mission, and to ensure consistency in forecasts. It is SWPC's goal to produce accurate and timely space weather products and decision-support tools that protect national critical infrastructure.

## Observation Platforms

NOAA's space weather products and services start with observations. NOAA uses an array of space- and ground-based observatories that use specialized instruments that support our space weather forecast operations and related research.

NOAA, through its National Environmental Satellite, Data, and Information Service, operates space-based observatories at three viewpoints to meet SWPC's operational requirements: deep space Lagrange point 1 (L1), the point located one million miles above the surface of the Earth for solar wind measurements; in geostationary orbit at 22,240 miles for key observations of solar flares, x-rays, and energetic particle radiation enhancements; and in low Earth orbit polar-orbit at 310 miles for measurements of the ionosphere. NOAA also ingests supplemental information by leveraging additional data from NASA research, and European research and operational satellites. NOAA is currently in the process of developing the Space Weather Follow-On (SWFO) program, which will provide mission continuity and augment capabilities at the L1 point and geostationary orbit.

Ground-based data are also important in SWPC operations. The underpinning data used by NOAA to supply geomagnetic storm warnings and alerts are the ground-based magnetic field observations provided by the USGS Geomagnetism Program. These observations describe the local intensity of the changes in magnetic fields and allow NOAA to characterize the intensity of geomagnetic storms. NOAA also relies on the USAF Solar Electro-Optical Network (SEON) and NSF's Global Oscillations Network Group (GONG). SEON provides continuous solar optical observations and solar radio emissions from ground stations around the world. GONG consists of a network of six stations that provide continuous solar imaging and magnetograms.

**Modeling and Product Dissemination**

Using these observations, forecasters predict the probability of eruptions on the Sun. When an eruption occurs, forecasters feed the data from the data collection platforms into computer models to determine the likely effects of solar events on Earth. The models help forecasters estimate when the effects will begin, how long they will last, and how severe the event will be. The model output will also provide critical infrastructure owners and operators with key decision points and thresholds for action, enabling more effective mitigation procedures and practices. NOAA is actively working with NASA and NSF to tap into their support of research and space weather modeling developed in the academic community to increase forecast skill.

NOAA is also pursuing a more effective Research-to-Operations-to-Research process through its new program, the Earth Prediction Innovation Center (EPIC). EPIC will utilize partnerships with academia, the private sector, and relevant agencies to validate and test new capabilities (e.g., products, models, observations, applications, and techniques), transition those capabilities from research to operations, and establish a process to evaluate and improve existing operational capabilities. As part of EPIC, space weather prediction models will benefit from the increased focus on enterprise collaboration.

NOAA forecasters communicate current and forecasted space weather conditions using a variety of products. Similar to the categories we use to classify hurricanes, there are also Space Weather Scales for communicating the relative severity of space weather storms. Space weather scales communicate potential impacts such as Radio Blackouts (from solar flares), Solar Radiation Storms (due to solar energetic particles), and Geomagnetic Storms (from coronal mass ejections). The scales list possible impacts for each level and indicate how often such events happen. Watches, warnings, and alerts are issued by email via a product subscription service and by telephone notification to critical customers such as power grid operators, FEMA, and Mission Control at NASA. NOAA's space weather alerts and warnings are essential for enhancing national preparedness for space weather.

In September 2019, NOAA and USGS announced the release of the new Geoelectric Field model. This model indicates the level of space weather impact affecting the U.S. electrical power grid and helps operators mitigate effects on critical infrastructure. The model relies on USGS magnetometers (described above), and work has already begun on improving the product to include Canada and to add a prediction capability that will rely on L1 measurements.

**Commercial Sector Engagement**

Additionally, NOAA continues to actively engage the commercial sector on opportunities to meet U.S. government requirements for weather and space weather information. NOAA ensures all space weather data, real-time and retrospective, and services are made available to the growing private sector service providers. The NOAA-private sector partnership plays a vital role in meeting the nation's needs for space weather services. NOAA recognizes that a strong public-private partnership is essential to establish the observing networks, conduct research, create forecast models, and supply the services necessary to support national security and economic prosperity. NOAA is committed to working toward the growth of the private sector as the national infrastructure demands more space weather services. These activities are governed by the NOAA Policy on Partnerships in the Provision of Environmental Information, NOAA Commercial Space Policy, and the NESDIS Commercial Space Activities Assessment Process. NOAA will continue to explore partnerships with the commercial sector as it maintains its operational capabilities to provide space weather awareness.

**NOAA's Interagency Coordination with SWORM**

On March 26, 2019, the National Science and Technology Council released the National Space Weather Strategy and Action Plan. This is an update to the original Strategy and Action Plan published in October 2015. The Strategy and Action Plan unites the U.S. national- and homeland-security enterprise with the science and technology enterprise to formulate a cohesive approach to enhance national preparedness for space weather. Key to the success of this update was input from the public on ways to leverage private capital and expertise on space weather research, observations, forecasts, and mitigation of effects on critical infrastructure. The National Science and Technology Council, Space Weather Operations, Research, and Mitigation

(SWORM) Interagency Working Group, comprised of over 20 Federal Departments and Agencies, is the interagency body that defines, coordinates, and oversees implementation of the objectives in the Strategy and Action Plan. This important update seeks to improve the government's coordination on long-term guidance for Federal programs and activities to enhance national preparedness to space weather events. The new strategy aligns with priorities identified by the Administration in the 2017 National Security Strategy and the Space Policy Directives.

NOAA appreciates the on-going support we have received from Congress for our critically-important space weather program. We will continue to collaborate with other Federal agencies and the private sector to develop and strengthen our activities in space weather research and forecasting. Thank you for the opportunity to testify today. I look forward to answering any questions you may have.

**William (Bill) Murtagh**
Program Coordinator
National Weather Service
National Oceanic and Atmospheric Administration

Bill Murtagh currently serves as the Program Coordinator for the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) in Boulder, Colorado. Bill is NOAA's space weather lead in coordinating preparedness and response efforts with industry, emergency managers, and government officials around the world. Bill also serves as the National Weather Service lead in the National Science and Technology Council (NSTC), interagency committee to develop and implement actions in the 2019 National Space Weather Strategy and Action Plan (NSW-SAP). He is the co-chair of the interagency space-weather working group responsible for implementing the NSW-SAP plans and procedures for responding to and recovering from space weather events. Bill is NOAA's lead in the National Security Council interagency committee responsible for the development and implementation of Executive Order 13865 - *Coordinating National Resilience to Electromagnetic Pulses.*

In November 2016, he completed a 26-month assignment in the White House Office of Science and Technology Policy (OSTP) as the Assistant Director for Space Weather. In his position at OSTP he oversaw the development and implementation of the 2015 National Space Weather Strategy and Action Plan and coordinated efforts to develop Executive Order 13744 (2016) – "Coordinating Efforts to Prepare the Nation for Space Weather Events".

He regularly briefs the White House, Congress, and other government leadership on vulnerabilities of critical infrastructure to space weather storms. Bill is also a key contributor in U.S. government efforts to advance international cooperation in space weather-related activities. He is a regular guest speaker at universities, government agencies, and national and international conferences. He has provided numerous interviews to major media outlets and is featured in several documentaries on space weather.

Before joining NOAA, Bill was a weather forecaster in the United States Air Force. He coordinated and provided meteorological support for national security interests around the world. Bill transferred to the SWPC in 1997 as a space weather forecaster and liaison between NOAA and the U.S. Air Force. He joined NOAA in 2003 after retiring from the Air Force with 23 years of military service.

Chairwoman FLETCHER. Thank you very much. Dr. Fox?

**TESTIMONY OF DR. NICOLA FOX, HELIOPHYSICS DIVISION DIRECTOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Dr. FOX. Chairwomen Horn and Fletcher, Ranking Members Babin and Marshall, and Members of the Subcommittees, it is an honor to appear before these Subcommittees today to discuss NASA's contributions to the understanding of space weather and its impact on society.

Space weather is the result of complex interactions between the sun, solar wind, Earth's magnetic field, and Earth's atmosphere. Our ability to understand and predict space weather is of growing importance to our Nation's economy, national security, and of course our NASA astronauts.

Through its Artemis program, NASA is accelerating its exploration plans to land the first woman and the next man on the surface of the Moon by 2024. To meet these objectives, we continue to accelerate development of the systems required to ensure success. The Artemis missions will send humans beyond the protection of Earth's magnetic field for the first time since Apollo and expose our astronauts and the systems upon which they will depend to a unique and potentially hazardous space weather environment.

NASA's Heliophysics Division is working with the Artemis program to support the human exploration of Deep Space and on approaches to measure the radiation environment on and around the Moon. These measurements will aid in the prediction and validation of the radiation environment in which our astronauts will be subjected.

Looking further into the future to journeys to Mars, NASA astronauts will need the capability to autonomously generate their own space weather data and predictions. To this end, the Heliophysics Division is working with the Space Radiation Analysis Group, or SRAG, at the Johnson Space Center on possible experiments in cislunar space to develop the science and technology needed for such predictions.

Artemis holds an important potential as a platform for scientific research. There is intense interest in what we can discover at the Moon. The lunar samples returned during the Apollo program dramatically changed our view of the solar system, and scientists continue to unlock new secrets from the samples. Artemis missions may include installation of space weather instruments on the Moon, and studies of the lunar surface could yield significant insights into the space weather over long time scales. There's just so much more to learn—knowledge that we can acquire with sustained human and robotic presence on the Moon.

NASA already addresses space weather impacts on astronauts and spacecraft while maintaining the International Space Station and protecting the astronauts living there. The Community Coordinated Modeling Center, or CCMC, team at Goddard Space Flight Center works with NOAA's Space Weather Prediction Center to provide data and forecast to the SRAG, who can then assess risks to the ISS. This experience will help NASA as we continue how to best protect Artemis astronauts from space weather impacts.

Space weather events are not only a concern for our astronauts and spacecraft, airline travel, communications, and precision navigation and timing systems like global GPS systems and the electrical power grid on which we depend every day can be impacted by space weather. The NASA Heliophysics Division continues to study the sun and how it influences the very nature of space, the atmospheres of planets, and in the case of Earth, the technology that exists in low-Earth orbit and on the surface.

The extensive dynamic solar atmosphere surrounds the sun, Earth, and planets and extends far out into the solar system. Mapping out this interconnected system requires a holistic study of the sun's influence. NASA has a fleet of spacecraft strategically placed throughout our heliosphere from Parker Solar Probe nearest the sun observing the very start of the solar wind, to satellites around Earth, including the Ionospheric Connection Explorer, or ICON, mission, which launched earlier this month, to the very farthest human-made objects, the Voyagers, which are still sending back observations on interstellar space. Each mission is positioned at a critical well-thought-out vantage point to observe and understand the flow of energy and particles throughout the solar system, and each provide a very different view of the complex system that leads to the space weather that we experience.

The research carried out by NASA's Heliophysics Division is improving our understanding of space weather. Working as the research arm of the Nation's space weather effort, NASA coordinates with NOAA, the National Science Foundation, and the U.S. Geological Survey, and of course the Department of Defense. NASA is also a member of the Space Weather Operations Research and Mitigations interagency working group run by the National Science and Technology Council, which coordinates interagency efforts to carry out the actions and meet the objectives identified in the Space Weather Strategy and Action Plan.

In support of the Nation's space weather effort, the Heliophysics Division has established the Space Weather Science and Applications, or SWxSA program, in collaboration with our sister Federal agencies, academia, and industry. The goal of this program is to effectively support the transition of heliophysics science results to applications that support our user communities and to provide improvements in space weather prediction models such as those used by SWPC. This activity also supports the interagency space weather efforts and is consistent with the recommendations of the 2013 decadal survey.

Furthermore, in coordination with NOAA, we have initiated a pilot program to expand the interagency capability and improve space weather products and services. We meet regularly with NOAA to develop this shared framework for research to operations, and as this matures, we will further integrate NSF, DOD, academia, and the private industry.

NASA really appreciates the continued support from these Committees, which ensures that the United States maintains a superior position in understanding space weather and is prepared to respond to space weather events. We look forward to continued collaboration with our sister agencies, international partners, academia, and industry, and I thank you very much for your invitation to be here with you. And I'm happy to answer any questions.

[The prepared statement of Dr. Fox follows:]

**HOLD FOR RELEASE**
**UNTIL PRESENTED BY WITNESS**
**OCTOBER 23, 2019**

**Statement of**
**Nicola Fox, PhD**
**Director, Heliophysics Division**
**Science Mission Directorate, NASA**
**before the**
**Subcommittee on the Environment and the**
**Subcommittee on Space and Aeronautics,**
**Committee on Science Space and Technology,**
**United States House of Representatives**

Chairwomen Horn and Fletcher, Ranking Members Babin and Marshall, and members of the Subcommittees, I am honored to appear before these Subcommittees to discuss NASA's contributions to understanding space weather and its impacts on our society.

Space weather is the result of complex interactions between the Sun, solar wind, Earth's magnetic field, and Earth's atmosphere. Our ability to understand and predict space weather is of growing importance to our nation's economy, national security, and even NASA Astronauts.

Through its Artemis program, NASA is accelerating its exploration plans and working to land the first woman and next man on the surface of the Moon by 2024. To meet these objectives, we continue to accelerate development of the systems required to ensure success. The Artemis missions will send humans beyond the protection of Earth's magnetic field for the first time since Apollo, and expose our astronauts and the systems upon which they will depend to a unique, and potentially hazardous space weather environment. NASA's Heliophysics division is working closely with the Artemis Program to support the human exploration of deep space, and on potential approaches to measure the radiation environment on and around the Moon. These measurements would aid in the prediction and validation of the radiation environment to which our astronauts will be subjected. Looking further in the future to journeys to Mars, NASA astronauts will need the capability to autonomously generate their own space weather data and predictions. To this end, the Heliophysics Division is working with the Space Radiation Analysis Group (SRAG) at the Johnson Space Center on possible experiments in cislunar space to develop the science and technology needed for such predictions.

Artemis holds important potential as a platform for scientific research. There is intense interest in what we can discover at the Moon. The lunar samples returned during the Apollo Program dramatically changed our view of the solar system, and scientists continue to unlock new secrets from the samples. We know the Moon can tell us more about our own planet, and even our Sun. Artemis missions may include installation of space weather instruments on the Moon, and studies of the lunar surface could yield significant insights into the space weather over long time scales. There is so much more to learn – knowledge we can acquire with a sustained human and robotic presence on the Moon. NASA will conduct many more science investigations and technology demonstrations on the Moon ahead of a human return through its Commercial Lunar Payload

Services (CLPS) initiative. Several payloads among those already selected through this program earlier this year will provide data of interest to solar and space physicists, and future payloads could include dedicated space weather instruments. The Artemis Program seeks to establish a sustainable architecture with our commercial and international partners on the Moon by 2028 and this architecture will support a future of scientific research.

NASA already addresses space weather impacts on astronauts and spacecraft while maintaining the International Space Station (ISS) and protecting the astronauts living there. The Community Coordinated Modeling Center (CCMC) team at the Goddard Space Flight Center works with NOAA's Space Weather Prediction Center (SWPC) to provide data and forecasts to the SRAG, who can then assess risks to the ISS. This experience will help NASA as it considers how best to protect Artemis astronauts from space weather impacts.

Space weather events are not only a concern for our astronauts and spacecraft; airline travel, communications and precision navigation and timing systems like the global positioning system (GPS), and the electrical power grid, on which we depend each day, can all be impacted by space weather. The NASA Heliophysics Division continues to study the Sun, how it influences the very nature of space, the atmospheres of planets and in the case of Earth, the technology that exists in low earth orbit and on the surface.

The extensive, dynamic solar atmosphere surrounds the Sun, Earth, and planets and extends far out into the solar system. Mapping out this interconnected system requires a holistic study of the Sun's influence. NASA has a fleet of spacecraft strategically placed throughout our heliosphere -- from Parker Solar Probe nearest the Sun, observing the very start of the solar wind, to satellites around Earth, to the farthest human-made object, Voyager, which is sending back observations on interstellar space. Each mission is positioned at a critical, well-thought out vantage point to observe and understand the flow of energy and particles throughout the solar system.

Several key missions are particularly focused on improving our understanding of space weather. The Parker Solar Probe, a first-of-its-kind mission, will visit the Sun's atmosphere, or corona, and provide information about coronal heating and the source of the solar wind. The Advanced Composition Explorer along with NOAA's Deep Space Climate Observatory observe the solar wind as it travels away from the Sun toward Earth and the other planets. The Solar Dynamics Observatory, the Solar and Terrestrial Relations Observatory, and the joint ESA/NASA Solar and Heliospheric Observatory all observe solar eruptions on the Sun. And finally, the Global-scale Observations of the Limb and Disk (GOLD) mission and the Ionospheric Connection (ICON) mission, launched earlier this month, will improve our understanding of what is happening in the ionosphere. Each of these missions provide a different view of the complex system that leads to the space weather we experience.

NASA Heliophysics works as the research arm of the nation's space weather effort, coordinating with NOAA, the National Science Foundation (NSF) and the U.S. Geological Survey, and Department of Defense (DoD). NASA is also a member of the Space Weather Operations, Research, and Mitigation (SWORM) Interagency Working Group run by the National Science and Technology Council, which coordinates interagency efforts to carry out the actions and meet the objectives identified in the National Space Weather Strategy and Action Plan. In addition to research missions, NASA supports improvements in space weather prediction models, such as those used by NOAA SWPC, the U.S. government's official source for space weather forecasts.

The NASA CCMC plays a key role in supporting our sister agencies by transitioning space research models to space weather operations.

NASA's Space Weather Science and Applications (SWxSA) project works to effectively support the transition of heliophysics science results to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. This activity supports interagency space weather efforts and is consistent with the recommendations of the 2013 Decadal Survey for Solar and Space Physics. Under SWxSA, NASA plans to competitively fund ideas and products, leverage existing agency capabilities, collaborate with other agencies, and partner with user communities. NASA established SWxSA in collaboration with sister federal agencies, academia and industry. Recent achievements include the award of grants that target research efforts to advance science priorities identified by our operational agency partner, investments in high end computing and the community coordinated modeling center.

Furthermore, in coordination with NOAA, we have initiated a pilot program to expand the interagency capability and improve space weather products and services for Research to Operations and Operations to Research (R2O2R). We are meeting regularly with NOAA to develop a shared framework for research to operations, and once we have established an effective and efficient process, we will further integrate NSF, DoD, academia and private industry into the framework.

NASA appreciates the continued support from these committees, which ensures that the United States maintains a superior position in understanding space weather and is prepared to respond to space weather events. We look forward to continued collaboration with our sister agencies, international partners, academia, and industry.

Thank you for the invitation to be here with you today, and I am happy to answer any questions you may have.

**Nicola Fox, Heliophysics Division Director**

Nicola Fox is the Heliophysics Division Director in the Science Mission Directorate at NASA Headquarters in Washington, DC. Until August 2018, Fox worked at the Applied Physics Lab at the Johns Hopkins University in Laurel, Maryland, where she was the chief scientist for Heliophysics and the project scientist for NASA's Parker Solar Probe – humanity's first mission to a star. She previously served as the deputy project scientist for the Van Allen Probes, and the operations scientist for the International Solar Terrestrial Physics program. Fox was born in Hitchin, Hertfordshire in England. She graduated from The Imperial College of Science, Technology and Medicine in London with a BS in Physics. She received an MS in Telematics and Satellite Communications from the University of Surrey. She then returned to Imperial College to complete a PhD in Space and Atmospheric Physics.

Chairwoman FLETCHER. Thank you, Dr. Fox. Admiral Lautenbacher?

**TESTIMONY OF DR. CONRAD C. LAUTENBACHER, JR., CEO OF GEOOPTICS, INC., AND FORMER UNDER SECRETARY OF COMMERCE FOR OCEANS AND ATMOSPHERE AND NOAA ADMINISTRATOR (2001–2008)**

Adm. LAUTENBACHER. Good afternoon, Chairman Fletcher and Chairman Horn, Ranking Members Marshall and Babin, and distinguished Members of the Subcommittees. It is my honor to appear before you today at this important hearing to discuss advancing research, monitoring, and the forecasting capabilities for space weather.

GeoOptics has been fulfilling its NOAA NESDIS (National Environmental Satellite, Data, and Information Service) contract under the Commercial Weather Data Pilot, CWDP, program and has successfully delivered over 350,000 high data accuracy GPS radio occultation profiles by the end of September 2019. Having successfully demonstrated our data, we look forward to NOAA NESDIS soon announcing its commercial data buy program.

Our success in demonstrating our technical capability to NOAA NESDIS would not have been possible without the leadership and support of many on this Committee and especially Congressman Frank Lucas, Congresswoman Suzanne Bonamici, and former Congressman Jim Bridenstine for their support of the Commercial Weather Data program in the *Weather Research and Forecasting Innovation Act of 2017*.

Our founder Tom Yunck originally proposed the GPS-RO (radio occultation) technique in 1988 and oversaw the development and improvement of the world's leading capability at the Jet Propulsion Laboratory known as JPL. Over the last decade, a series of government-funded satellites have refined the RO technology and proven out its tremendous capability. GeoOptics CICERO, which stands for Community Initiative for Cellular Earth Remote Observation, nanosatellites, is the only U.S.-based RO provider with the JPL gold standard for some of the most accurate weather and climate data available, offering significantly more impact per measurement than traditional weather instruments.

We have worked with our partners at the Jet Propulsion Laboratory and Tyvak Nano-Satellite Systems to commercialize and miniaturize this technology. By launching smaller, less expensive satellites, we will be able to make orders of magnitude more data available to weather forecasters and scientists around the world. And our pledge to the scientific community is that all CICERO data will be provided free for any research purpose.

Radio occultation data provides high-resolution temperature and water vapor profiles by getting measurements of bending angle profiles in the troposphere and the stratosphere with high vertical resolution and accuracy. The measurement of bending angles can be used to obtain information on refractivity profiles which can be used to retrieve atmospheric temperature and humidity profiles, as well as surface pressure. Another objective is to provide space weather information through measurement of electron density and its profile in the middle and high atmosphere.

There is a robust interest from other private-sector space weather technology companies to work with Federal agencies to develop and implement solutions to deal with space weather. For example, GeoOptics is a member of the American Commercial Space Weather Association, commonly known as ACSWA, which is comprised of 19 member companies with the common goal of developing, delivering, and sustaining key space weather products and services to mitigate threats to societal infrastructure.

ACSWA plays an essential role in the academic, governmental, commercial triad that forms the space weather enterprise. ACSWA companies provide the insight, innovation, and cost benefits to our Nation's preparedness and responsiveness to space weather threats. ACSWA is a collective voice for the commercial space weather sector and an advocate for the enterprise.

Since its inception in 2010, beginning with five companies, ACSWA has quadrupled in size. ACSWA serves as a catalyst for collaboration between various organizations and the commercial space weather industry. ACSWA works with government agencies, academia, and industry stakeholders to strengthen the space weather enterprise and to promote space weather, space weather partnerships, and public commercial initiatives.

Last year, NOAA NESDIS issued its final report of the NOAA Space Platform Requirements Working Group, the SPRWG, in support of the NOAA Satellite Observing System Architecture study. As a part of this study, NESDIS initiated the Space Platform Requirements Working Group, commonly known as the SPRWG, to evaluate the future needs and relative priorities for weather, space weather, and environmental remote sensing, including land mapping, space-based observations for the 2030 timeframe and beyond.

One has only to look at the ranking of the space weather measurements that were identified by leading NOAA and university research scientists in the SPRWG report and compare them to the technological capabilities offered by ACSWA members.

Increased investments are needed from Congress to continue to fund the commercial data buy program for GPS R.O. data that benefit nowcasting and commercial weather prediction. Congress should also consider a commercial space weather data program for commercial sectors to provide cost-effective solutions for the challenges of space weather as defined in the NOAA SPRWG report.

The American Commercial Space Weather Association and its member companies look forward to working with Congress and Federal agencies in advancing their knowledge and understanding of space weather. Thank you for your consideration. I will do my best to address any questions you may have. Thank you.

[The prepared statement of Adm. Lautenbacher follows:]

**Written Testimony before the**
**U.S. House of Representatives, Space, Science and Technology Committee,**
**Subcommittee on Environment and Subcommittee on Space and Aeronautics**

**Joint Hearing Entitled:**
**"Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities"**

**Dr. Conrad C. Lautenbacher, Jr., VADM USN (Ret.),**
**Chief Executive Officer -- GeoOptics, Inc.**
**Executive Committee Member -- American Commercial Space Weather Association**

October 23, 2019

Good Afternoon -- Chairman Fletcher and Chairman Horn, Ranking Members Marshall and Babin and distinguished Members of the Subcommittee, it is my honor to appear before you today at this important hearing to discuss Advancing Research, Monitoring, and the Forecasting Capabilities for Space Weather.

GeoOptics has been fulfilling its NOAA NESDIS contract under the Commercial Weather Data Pilot (CWDP) program and has successfully delivered over 350,000 high data accuracy GPS-Radio Occultation profiles by the end of September 2019. Having successfully demonstrated our data, we look forward to NOAA NESDIS soon announcing its Commercial Data Buy Program.

Our success in demonstrating our technological capability to NOAA NESDIS would not have been possible without the leadership and support of many on this committee and especially Congressman Frank Lucas, Congresswoman Suzanne Bonamici and former Congressman Jim Bridenstine for their support of the Commercial Weather Data Program in the Weather Research and Forecast Innovation Act of 2017.

Our founder Tom Yunck originally proposed the GPS-RO technique in 1988 and oversaw the development and improvement of the world's leading capability at the Jet Propulsion Laboratory. Over the last decade a series of government-funded satellites have refined the RO technology and proven out its tremendous capability. GeoOptics' CICERO (Community Initiative for Cellular Earth Remote Observation) nano-satellites is the only US-based RO provider with "the JPL gold standard" for some of the most accurate weather and climate data available, offering significantly more impact per measurement than traditional weather instruments.

We have worked with our partners at the Jet Propulsion Laboratory and Tyvak Nano-Satellite Systems to commercialize and miniaturize this technology. By launching smaller, less expensive satellites, we will be able to make orders of magnitude more data available to weather forecasters and scientists around the world. And, our pledge to the scientific community is that all is CICERO data will be provided free for any research purpose.

Radio Occultation data provides high-resolution temperature and water vapor profiles by gaining measurements of bending angle profiles in the troposphere and the stratosphere with high vertical resolution and accuracy. The measurement of bending angles can be used to obtain information on refractivity profiles, which can be used to retrieve atmospheric temperature and humidity profiles, as well as surface pressure. A secondary objective is to provide space-weather information through measurement of electron density and its profile in the middle and high atmosphere.[1]

There is a robust interest from other private sector / space weather technology companies to work with federal agencies to develop and implement solutions to deal with Space Weather. For example, GeoOptics is a member of the American Commercial Space Weather Association (ACSWA), which is comprised of 19 member companies with the common goal of developing, delivering, and sustaining key space weather products and services to mitigate threats to societal infrastructure. ACSWA plays an essential role in the academic-governmental-commercial triad that forms the space weather enterprise. ACSWA companies provide the insight, innovation, and cost-benefit to our Nation's preparedness and responsiveness to space weather threats.[2]

ACSWA is a collective voice for the commercial space weather sector and an advocate for the enterprise. Since its inception in 2010 beginning with five companies, ACSWA has quadrupled in size. ACSWA serves as a catalyst for collaboration between various organizations and the commercial space weather industry. ACSWA works with government agencies, academia, and industry stakeholders to strengthen the space weather enterprise and to promote space weather, space weather partnerships, and public/commercial initiatives.

Last year NOAA NESDIS issued its final report of the NOAA Space Platform Requirements Working Group (SPRWG) in support of the NOAA Satellite Observing System Architecture (NSOSA) study. As a part of this study, NESDIS initiated the Space Platform Requirements Working Group (SPRWG) to evaluate the future needs and relative priorities for weather, space weather and environmental remote sensing (excluding land mapping) space-based observations for the 2030 timeframe and beyond. [3]

One has only to look at the ranking of the space weather measurements that were identified by leading NOAA and university research scientists in the SPRWG Report and compare them to the technological capabilities offered by ACSWA member companies. [4]

Increased investments are needed from Congress to continue to fund the Commercial Data Buy Program for GPS-RO data that benefit Nowcasting and Numerical Weather Prediction.

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[1] https://www.eumetsat.int/website/home/Satellites/FutureSatellites/EUMETSATPolarSystemSecondGeneration/RO/index.html
[2] http://www.acswa.us/about.html
[3] https://www.nesdis.noaa.gov/sites/default/files/SPRWG_Final_Report_20180325_Posted.pdf.
[4] http://www.acswa.us/capabilities.html

Congress should also consider creating a Commercial Space Weather Data Program for commercial sector providers to provide cost effective solutions for the challenges of Space Weather as defined in the NOAA SPRWG Report.

Jet Propulsion Laboratory and California Institute of Technology scientists [5]recommended: "...Cubesat swarms, either as a dedicated constellation or an ad-hoc constellation deployed via launches of opportunity, would be a profoundly useful resource for advancing Atmosphere-Ionosphere-Magnetosphere science, providing plasma measurements to accompany other measurements of the forces that influence ionospheric structure such as solar extreme ultraviolet radiation (EUV), thermo-spheric winds and composition, and ionospheric electric fields." That was written in 2010 and many of these recommendations are included in the recommendations of NOAA SPRWG Report that was issued in 2018.

My esteemed panelists could better answer this point, but if the United States were to suffer a huge coronal mass ejection like the 1859 Carrington Event in Missouri, conservative estimates would be around $20 Trillion for the US to manage the destruction from a massively crippling solar storm on our electronic infrastructure[6]. Therefore, it is critically important in the Nation's vital self-interest to find solutions to the challenges of Space Weather that could adversely affect life here on Earth.

The American Commercial Space Weather Association and its member companies look forward to working with federal agencies advance their knowledge and understanding of Space Weather.

Thank you for your consideration. I will do my best to address any questions that you may have.

[5] GNSS1 Geospace Constellation (GGC): A Cubesat Space Weather Mission Concept Anthony J. Mannucci, Jeff Dickson, Coutney Duncan, Ken Hurst Jet Propulsion Laboratory, California Institute of Technology

[6] https://www.sciencealert.com/here-s-what-would-happen-if-solar-storm-wiped-out-technology-geomagnetic-carrington-event-coronal-mass-ejection

## Conrad C. Lautenbacher, Jr.

Retired Navy Vice Admiral Conrad C. Lautenbacher, Ph.D., serves as Chief Executive Officer and Director for GeoOptics, Inc., a startup company with the initial goal of launching and operating the first commercial Radio Occultation (RO) satellite constellation designed for the express purpose of collecting and offering weather data and associated services as a commercial enterprise. Most recently, as Vice President, Science Programs, Applied Technology Group (ATG) of CSC Corp. he was engaged in business development activities to expand opportunities in science and technical support operations.

He previously served as Under Secretary of Commerce for Oceans & Atmosphere and Administrator of the National Oceanic and Atmospheric Administration (NOAA) for seven years. Prior to that, he was President and CEO of the Consortium for Oceanographic Research and Education (CORE), now known as the Consortium for Ocean Leadership. Before joining CORE, Dr. Lautenbacher formed a consulting business, CEREBRUM, Inc. and worked principally for defense industries.

Notable navy assignments included Commander US Third Fleet, Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments), Director of J-8 (Resources) on the Joint Staff., Commander Naval Station Norfolk, the Navy's largest naval station, Commanding Officer of USS HEWITT (DD-966), Commander Cruiser Destroyer Group Five, and Commander, Naval Forces, Riyadh during Operation Desert Storm.

He holds Master of Science and Ph.D. degrees from Harvard University in Applied Mathematics and is a graduate of the US Naval Academy (Class of 1964).

# WRITTEN TESTIMONY OF DR. HARLAN E. SPENCE, DIRECTOR, INSTITUTE FOR THE STUDY OF EARTH, OCEANS, AND SPACE, AND PROFESSOR OF PHYSICS AND ASTRONOMY, UNIVERSITY OF NEW HAMPSHIRE

**Statement of Dr. Harlan E. Spence**
University of New Hampshire
Director, Institute for the Study of Earth, Oceans, and Space (EOS)
and Professor of Physics and Astronomy
*Space Studies Board (SSB), National Academies of Sciences, Engineering and Medicine (NASEM)*
*University Corporation for Atmospheric Research (UCAR), Board of Trustees*
*Fellow, American Association for the Advancement of Science (AAAS)*

**Before the Joint Subcommittees on Environment and on Space and Aeronautics**
**U.S. House of Representatives**

6 November 2019

Chairs Fletcher and Horn, Ranking Members Marshall and Babin, and members of the Subcommittees, I should like to thank you for the opportunity to submit written testimony following the hearing on "*Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities*". My name is Harlan Spence. I am a Professor of Physics and Astronomy and also the Director of the Institute for the Study of Earth, Oceans, and Space (EOS) at the University of New Hampshire (UNH). I am a member of the National Academy of Sciences, Engineering, and Medicine Space Studies Board, a member of the Board of Trustees of the University Corporation for Atmospheric Research, and a Fellow of the American Association for the Advancement of Science. The views I present today are my own. They are rooted in my 30 years of first-hand experience as a space physicist and space weather researcher.

The intent of my testimony is twofold: first, to provide insights on what the academic community brings to bear on the critically important issue of space weather; and second, to explain why those research efforts are so vital to our nation's space weather monitoring and forecasting capabilities. I am increasingly compelled by such research because space weather poses profound risks to the protection of life and property. I am thus grateful for the bipartisan support that space weather currently enjoys, and I urge that Congress move forward expeditiously with legislation that establishes a coordinated, multi-agency approach to supporting space weather research and forecasting.

In brief, the points I wish to make today are as follows:

1. **Fundamental solar and space physics research (theory, modeling, and observations) plays a critical role in improving our space weather prediction capabilities.**
2. **Because space weather involves processes occurring across vast distances and connecting different regions, advancing space weather demands support for a wide suite of observations (space-based, ground-based, large platforms, small platforms, etc.) spanning both basic research and monitoring.**
3. **The academic community contributes to closing current and emerging observational gaps needed to advance space weather predictability.**
4. **Space weather forecast capability would advance more rapidly by strengthening the two-way pipeline connecting basic research to space weather operations.**
5. **Government-wide policy is needed to enable relevant agencies to work collaboratively and concertedly on innovative mechanisms for addressing space weather-related challenges.**

Before elucidating these points, let me begin by describing space weather from an academic's point of view. Space weather refers to variations in the environments connecting the Sun with the Earth's surface, particularly those variations that harmfully impact systems, technologies, and/or humans whether in space or on the ground. Those environments include: the Sun's visible surface, where sunspots are observed; the solar corona, the Sun's extremely hot outer atmosphere; the solar wind, the magnetized plasma wind that blows away from the Sun, filing the solar system, and constantly buffeting the planets; the Earth's magnetosphere, which acts not only like a solar wind shield but also like a bottle for space weather effects; the Earth's ionosphere, the electrically conducting layer in the upper atmosphere; and the Earth's surface itself, which represents another electrically conducting surface. The Sun and Earth are separated by vast distances, yet they remain highly interconnected through the processes which drive space weather throughout this complex system.

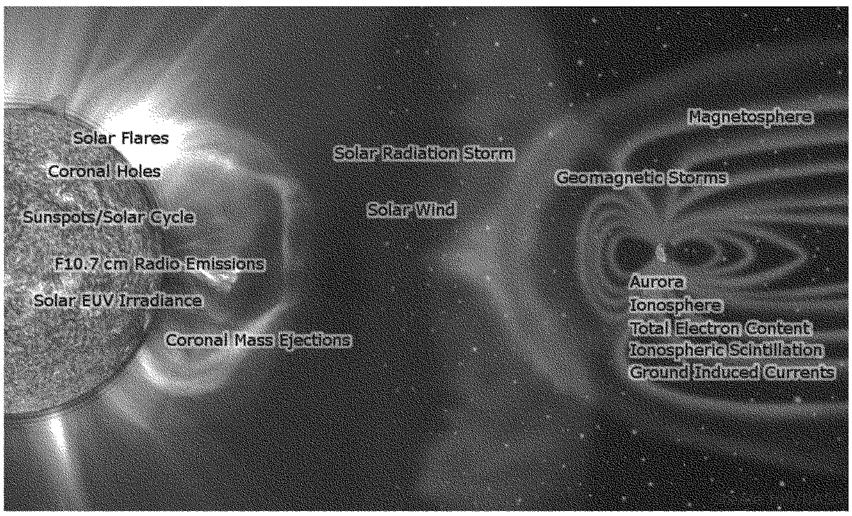

*Image credit: NOAA Space Weather Prediction Center (https://www.swpc.noaa.gov/phenomena)*

Most but not all space weather phenomena originate at the Sun. Two examples of space weather phenomena of solar origin include: solar flares (which spawn solar radiation storms and radio blackouts) and coronal mass ejections (which power geomagnetic storms and pose threats to the power grid). Two examples of space weather phenomena of non-solar origin include galactic cosmic rays (a second form of space radiation which is modulated by solar activity and important for human exploration) and ionospheric scintillations (which can disrupt radio waves traveling through the atmosphere). Basic science questions about the mechanisms which underpin these space weather phenomena either remain unanswered or our understanding is primitive. Without that fundamental scientific understanding, space weather predictability remains understandably poor. Since the dawn of the space age, we have learned a tremendous amount about space weather, however, we remain a long way from being able to predict and mitigate its effects, or even to understand the range in amplitude of space weather effects so that resilience might be economically engineered into technological system designs.

1. **Fundamental solar and space physics research (theory, modeling, and observations) plays a critical role in improving our space weather prediction capabilities.**

The academic space weather community conducts basic research on these regions and processes with support principally from NASA and NSF. The importance of these partnerships to advancing our fundamental understanding of space weather was explicitly validated throughout the 2013 National Academies Decadal Survey in Solar and Space Physics[1]. At NASA, this basic research is supported through missions and supporting research and technology funded through principally the Heliophysics Division in the Science Mission Directorate (SMD). At NSF, this research is supported through the Geospace Section in the Division of Atmospheric and Geospace Sciences (AGS) in the Geosciences (GEO) Directorate. Let me provide representative examples from my own programs that illustrate how the academic community is advancing scientific understanding to the point of predictability.

I begin with the NASA Van Allen Probes mission, part of the Heliophysics Living with a Star program. Van Allen Probes has fulfilled its goal of "understanding (to the point of predictability) how populations of relativistic electrons and ions in space form or change in response to changes in solar activity and the solar wind." The Van Allen radiation belts encircle the Earth and pose a radiation threat to satellites that orbit through them. Before the mission began, the space physics community believed we understood their basic structure and their overall variability. As it nears its end, the Van Allen Probes mission has revealed structure to the belts never imagined[2], quantified the waxing and waning of "killer" electrons in the outer belt[3], and differentiated between the relative importance of various physical mechanisms that sculpt the belts and its variability[4]. Whereas before the mission belt predictability was poor – some storms would increase the belts, some would decrease the belts, and some would have no effect – we now know the various competing factors at work, and how they are in a constant tug of war on the belt that powers belt dynamics. That fundamental understanding is leading to improved models which rely on observations to drive them.

I am privileged and honored to be a Principal Investigator (PI) on Van Allen Probes. I led a multi-institution team, including other academic institutions, national labs, and FFRDCs, who designed, built, operated, and analyzed data from an instrument suite measuring the charged particles within the radiation belt environments[5]. I was joined by three other PIs, all from other academic institutions, who provided the complementary instruments needed to accomplish mission science. This is a powerful example of the strong partnership that NASA and the academic community have in accomplishing Decadal Survey priorities. This mission has rewritten the textbook on radiation belt physics and ushers in a new degree of predictability of this perilous region. With NASA's support and partnership, the academic community has played a major role in advancing the basic science that undergirds radiation belt predictability.

The Magnetospheric Multiscale (MMS) mission represents an example of another relevant NASA mission on which I am involved, this one in the Heliophysics Solar Terrestrial Probes (STP) program. MMS is very much a mission focused on the fundamental physics of a process known as magnetic reconnection. Reconnection is the basic plasma physical process by which energy stored in magnetic fields is converted into particle energy. Although magnetic reconnection is itself not a space weather threat, it a critical process that initiates and controls the evolution of space weather events. The MMS mission is peering deeply into the microphysics of magnetic reconnection to understand its origins and energetics. That understanding is important for many basic science reasons, but in the context of space weather, such knowledge is required so that the effects of reconnection can be accurately included in space weather models.

I am also privileged and honored to be a PI on another NASA mission, the Lunar Reconnaissance Orbiter (LRO) mission within the Planetary Science Division of SMD. The instrument I lead, called the Cosmic Ray Telescope for the Effects of Radiation or CRaTER, is a dual-use instrument[6]. It not only explores the Moon's surface properties, but also quantifies the space radiation impacts of robotic and human explorers in deep space to galactic cosmic rays and to solar particles generated by solar eruptive events. Having now operated over a full 11-year solar cycle, CRaTER observations are being used not only to quantify current and past radiation exposure to space radiation[7,8], but also through modeling to peer ahead[9]. We are on the verge of answering whether our current space age high in radiation danger will continue to increase. We have also developed a new quantitative measure of solar particle events for monitoring deep space radiation threats. This is another example in which the academic community, in partnership with NASA, advances theory, modeling, and observational capabilities to improve our space weather prediction capabilities that will increase the safety of both government- and commercially-funded human exploration.

Let me now turn to the NSF. Several years ago, I was PI on an NSF GEO Frontiers of Earth Systems Dynamics award called "Sun-to-Ice". Coinvestigators were drawn from other academic institutions, FFRDCs, and the commercial sector. The project goal was to establish if we might use indicators in the geologic record to unravel the unknown mysteries of past solar activity. This is important for space weather given that we have only seen the Sun's full fury from space-based measurements over the past ~50 years, a very brief moment in the Sun's complete history. We currently have only a vague understanding of how active the Sun may have been in the past, as an indicator of how much more active it might be in the future compared to the present day This highly interdisciplinary team concluded that while initially promising, certain signals observed in ice cores are not reliable indicators of past solar activity[10]. This is unfortunate as this technique had earlier been adopted as a working indicator for solar extremes by communities seeking practical engineering solutions to space weather impacts. As a result of this project, we are now actually less certain on the extreme values, which makes it more important than ever to develop our physical understanding of the origins of solar extremes to the point of predictability. Our community continues to explore other solar proxies in the geologic record, inspired by this project. Until then, we are comparatively blind to what the future might hold in terms of extreme space weather events.

2. **Because space weather involves processes occurring across vast distances and connecting different regions, advancing space weather demands support for a wide suite of observations (space-based, ground-based, large platforms, small platforms, etc.) spanning both basic research and monitoring.**

On the one hand, advancing the basic science at the core of space weather requires observations that are driven strongly by the requirements needed for science closure. These strategic observations are needed to advance our understanding of the basic processes which drive space weather. The Van Allen Probes observations are one example of observations that are needed to reach closure on a set of science questions.

On the other hand, space weather prediction requires observations driven instead by the needs for continuous monitoring of key environment variables that are inputs to models for forecasting or nearcasting. An example of this kind of variable demanding operational observation is the direction of the interplanetary magnetic field (IMF) entrained in the solar wind upwind of the Earth. The IMF orientation acts like a switch, more or less allowing or preventing solar wind energy to power geomagnetic storms at Earth. When the IMF points toward the south, the switch is "on"; when it is north, the switch is "off". At present, this key variable (IMF orientation) used to drive geospace models is not predictable in any practical manner. Instead, models that use this key variable as an input rely on an upstream monitor of the IMF at a location called the forward Lagrange point (L1) between the Sun and the Earth, but comparatively closer to the Earth.

A robust space weather program must accommodate both needs: science, to advance understanding; and operational, to advance forecasting. There are many examples that demonstrate how both interests are served in a single system (c.f., NASA's ACE spacecraft providing real-time L1 space weather data products for the space weather prediction community as well as accomplishing mission science). However, as our understanding of the connectedness of the space weather environment grows, there is an increasing awareness that both scientific understanding and predictability require simultaneous observations of the whole system, literally from Sun to Earth. NASA's Heliophysics System Observatory (HSO) clearly demonstrates this concept, the notion that more science can be done through a collection of missions in concert rather than individually. Indeed, how individual missions contribute to the HSO is an important factor in the NASA mission Senior Review prioritization process.

This forward-looking approach to balancing science and operations observations is not always possible given funding realities. For instance, at the NSF, ground-based neutron monitors have long been used as a standard measure at Earth's surface of the radiation environment in deep space. Our national network of neutron monitors, even though important to space weather operations, have been funded principally through scientific research grants to individual institutions. Each station runs the peril of going offline if the science proposal that funds its operations is not funded. I believe we can do a better job across the government in supporting appropriately those observations that have a dual purpose, and I am encouraged by congressional language that would foster that important paradigm shift.

3. **The academic community contributes to closing current and emerging observational gaps needed to advance space weather predictability.**

The academic community has been at the forefront in developing CubeSats for space weather research. The NSF CubeSat program, run out of AGS, continues to provide opportunities for the academic community to propose missions to fill targeted space weather knowledge gaps. I am delighted to be the PI of one such set of missions called FIREBIRD. In combinations with Montana State University and The Aerospace Corporation, we developed two missions (FIREBIRD-I, and -II) comprising four CubeSats in two sets of pairs. The science goal of FIREBIRD was to quantify how relativistic electrons from the radiation belts "precipitate" into Earth's upper atmosphere[11]. While an extremely small mission cost, FIREBIRD-II continues to play a pivotal role in understanding radiation belt dynamics synergistically with other contemporaneous CubeSat missions, NASA balloon missions, the Van Allen Probes missions, and international missions to the radiation belts[12]. Precipitation loss of the radiation belts to the atmosphere is a key factor in belt dynamics, and the FIREBIRD mission (along with the others mentioned above) provide a key measurement enabling an observational gap remaining even after the Van Allen Probes mission.

Both the initial NSF and the subsequent NASA CubeSat programs provide opportunities not only for the academic program to fill key observational gaps in a rapid fashion, but it also provides a remarkable opportunity to train the next generation of this country's spacecraft engineers and operators and space weather scientists. These values have been described well in the 2016 National Academy report entitled "Achieving Science with CubeSats: Thinking Inside the Box[13]."

4. **Space weather forecast capability would advance more rapidly by strengthening the two-way pipeline connecting basic research to space weather operations.**

Transitioning research to operations (or R2O) is often referred to as an uncrossable valley of death. It is no less a challenge in space weather as in other disciplines. In the past, it suffered from a combination of lack of funding for such transitioning in the research community, and a lack of staffing in the operations community to support the transition. Of course, it is further challenged by different mindsets and goals of the "R" and the "O" communities in terms of model development and use. I believe that the space physics and space weather community have done an outstanding job in advancing on this front, partly owing to lessons learned from other communities, and the emergence of such venues as the Space Weather Workshop, wherein the science, operations, and end-user communities convene annually to align needs and capabilities.

The Earth-Moon-Mars Radiation Environment Model (EMMREM) is an example of a UNH-developed science model[14] that transitioned to a space weather operational model. EMMREM is now a community access tool at the Community Coordinated Modeling Center at NASA's Goddard Space Flight Center. EMMREM grew out of studies of the spatial, temporal, and energetic evolution of solar particle events throughout the solar system, combining observations throughout the heliosphere with simulations of energetic particle transport. Informed by the underlying science and inspired by the prospects of human exploration to deep space, EMMREM applies the science of energetic particles by estimating time-dependent radiation exposure relevant to human deep space exploration[15].

However, without deliberate funding from NASA, EMMREM would not have been possible. The same is true for any number of other science models which have been transitioned to space weather operations. Furthermore, as difficult as it is to transition research to operations, a robust pipeline must allow operations to inform the research, thus closing the R2O-O2R circle. While there have been early successes, such as EMMREM and other models developed within academia, improved progress in space weather forecast capability rests also on mindfully supporting an even stronger R2O-O2R pipeline. I commend NASA for its new Space Weather Science and Applications (SWxSA) program which is a step in the right direction.

5. **Government-wide policy is needed to enable relevant agencies to work collaboratively and concertedly on innovative mechanisms for addressing space weather-related challenges.**

Twenty years ago, I recall doing a TV interview about Y2K and in that context, I remarked that space weather was likely a bigger threat to human technologies than how computer timekeeping accounted for the change to a new millennium. Many in the space physics community shared a common view even two decades ago. Since that time, my appreciation of the threats of space weather has grown along with our understanding not only of the frequency of extreme space weather events, but also at the vulnerability of our space-aged technologies. Whereas in the year 2000, I viewed space weather as a potential risk that should be studied, it is now a true threat that should keep us up all night. With each new study we learn that it is not a question of "if" but a question of "when" we will have a historically large magnetic storm[16,17]. National Academy reports[18] outline the vulnerabilities of our power grid, and the dire ripple effects to society that a continent-wide grid failure would produce, with threats to our security, properties, and lives. This modern awakening to the threat is why I believe we need a rapid and coordinated approach to space weather prediction.

As I have attempted to convey in this testimony, the issue of space weather is enormously complicated and multifaceted. Multiple administrations have sought to bolster our space weather observational capabilities through various White House initiatives such as those put forth by the Space Weather Operations, Research, and Mitigation (SWORM) Working Group. Likewise, individual agencies like NASA, NSF, and NOAA have focused what resources and attention they can spare on this topic. These actions are commendable. However, they have not resulted in the capability required to reliably predict and effectively mitigate against the hazards posted by space weather to our economy and national security, not to mention our astronauts in space.

My experience working on this topic in partnership with federal agencies convinces me that a more unified approach, sustained over the long term, is required. A government-wide policy, perhaps codified in legislation, is needed to clearly delineate roles and responsibilities, enabling agencies to leverage their unique attributes in concert to accelerate the development of a stronger and more resilient space weather regime. An emphasis must also be placed on consistency, but with careful consideration of the fact that agencies require flexibility to adequately adapt to rapidly changing scientific, technological, and policy landscapes.

As a member of the scientific community, I can speak to the value of employing external partnerships to meet the needs described above. This includes collaborations wherein a federal agency leverages the unique science and engineering capabilities of universities and private companies to develop new low-cost instruments and platforms for rapidly filling observational gaps. Additionally, such mechanisms can help spur multidisciplinary collaborations that advance our understanding of space weather through the application of artificial intelligence, data science, and other computational tools. Multi-sectoral collaborations like this can also be particularly impactful to R2O-O2R because they offer federal agencies the opportunity to focus the individual strengths of participating entities toward translating research advances into new technologies that strengthen our readiness and resilience. Finally, involving academic institutions in such arrangements allows students and faculty to conduct hands-on, cutting-edge research in solar and space physics. Such opportunities contribute to the workforce development pipeline and ensure the long-term vitality of disciplines relevant to space weather.

I look forward to providing any additional information or assistance you may ask of me, including responses to questions for the record. I sincerely appreciate the opportunity to provide testimony on space weather, specifically the role of universities in advancing research, monitoring, and forecasting capability for the Nation.

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Chairwoman FLETCHER. Thank you very much. At this point we will begin our questions. We'll begin our first round, and I'm going to start recognizing myself for 5 minutes.

First question really goes to solar wind data and DSCOVR, so NOAA's Deep Space Climate Observatory, or DSCOVR, satellite is a partnership between NOAA, NASA, and the U.S. Air Force to provide real-time solar wind data and to succeed NASA's Advanced Composition Explorer or ACE satellite, which is beyond its expected lifetime. It was launched in 2015 with an expected lifetime of 5 years but has been in a safe-hold mode since June of this year and is no longer transmitting data, leading NOAA to revert back to collecting solar and wind data from ACE.

Mr. Murtagh, how critical are real-time solar wind observations to the development of space weather forecasts?

Mr. MURTAGH. They are indeed critical. We consider those measurements at L1; it's our sentinel in space. When the coronal mass ejection leaves the sun, we can see—other instruments we use to observe it, that it's actually—or directed. We really can't dissect it. We don't know what's in that CME (coronal mass ejection) until it hits the L1 point. And key to the measurements at L1 is the orientation of the magnetic field because what the sun just shot out into space was a magnet. A coronal mass ejection is a big magnetic field and Earth is a magnetic field. The two magnetic fields are going to come together, and how they couple together is going to dictate how intense the geomagnetic storm response will be.

Once it passes that spacecraft, we have a sense for exactly what the field is going to look like, and we immediately notify, especially the electric power grid operators around this country, just how big the storm is likely to be. So we depend on that absolutely.

Chairwoman FLETCHER. And this is a question for you and for Dr. Fox. What other avenues of receiving solar wind data are available if NOAA is unable to get DSCOVR back online and the ACE satellite stops transmitting data?

Mr. MURTAGH. None really. We are essentially blind if we lose the ACE data and the DSCOVR data.

Chairwoman FLETCHER. Dr. Fox, do you want to weigh in on that?

Dr. FOX. So we would be blind until 2024. In 2024, NASA will launch the IMAP (Interstellar Mapping and Acceleration Probe) mission, which is a mission really dedicated on looking at the outside of our heliosphere and the boundary to interstellar space. But we will carry with us the NOAA Space Weather Follow-On L1 observatory as a rideshare. And so once we're out there in orbit, then that gap would be filled, but Bill is completely correct. Between those two events, there really is no way of getting anything out there either.

Chairwoman FLETCHER. OK. And are there any other long-term contingency plans for getting solar wind data beyond what you've described, either this program in 2024 or the existing data collection mechanisms?

Mr. MURTAGH. Yes. It's fortunately very much recognized by NOAA the importance of this data. So we're pursuing, as Dr. Fox just mentioned, a 2024 launch, but we've also just released a Broad Area Announcement to the world, if you will, where we want to look at what we should have as a follow-on. So we've already begun the process of looking at what we need to have up there after the IMAP mission.

Chairwoman FLETCHER. OK. Thank you. Switching gears a little bit, I do want to talk with the remaining time I have left about our investments in space weather and want to ask in your estimation what is the current Federal investment in research compared to operations for space weather? And what should the ratio of investment be in order to substantively improve our forecasting capabilities?

Mr. MURTAGH. So I would say our budget at SWPC is about $11 million or thereabouts, but one has to recognize that a considerable amount of funds go to the observation platforms within NOAA both at the DSCOVR, the L1 commitment, and of course our spacecraft at geosynchronous orbit also very, very, very much critical for the provision of space weather services for the Nation.

I think an awful lot of money goes toward the research, but so it should. You may have heard in the past about us being about 30 to 50 years behind the meteorology community. It's largely because the fundamental research necessary to better understand the processes of the sun and the eruptions on the sun and how they interact with the Earth, there is so much research still necessary to get us where we need to be.

Chairwoman FLETCHER. OK. Dr. Fox, do you want to weigh in on that before we wrap up?

Dr. FOX. Also the sheer space that we have to cover is very different. The sun is 93 million miles away, and there is a—you know, so it is easy to say we are behind the terrestrial weather, but there is an awful lot more space to cover which makes it very important for us to have continued measurements covering that full area.

Chairwoman FLETCHER. Thank you so much. And I have gone over my time, but I thank you for your answers to my questions. And I will now recognize Mr. Marshall for 5 minutes.

Mr. MARSHALL. Thank you, Chairwoman. My first question for Mr. Murtagh, I mentioned in my opening statement the importance of precision agriculture, precision agriculture for Kansas farmers and ranchers and the dependence upon data from satellites in orbit. Has NOAA reached out to any agriculture groups, any opportunities there that you would like to educate us on?

Mr. MURTAGH. Yes. Perhaps I could answer that with a little story. Five or 6 years ago we got contacted by a company that develops the machinery for our farming. And we'd had a space weather event a few weeks earlier, and they got all sorts of calls from their customers trying to figure out why their GPS-dependent technology was not working so well. The company realized there was a space weather event. They reached out to us. They said could we get the information to them and they in turn would redistribute it to all their customers.

And we saw that as a great way of doing it, so we followed up with them and others as much as we can, the folks that make the machinery, that make the equipment that goes into that machinery, the GPS-dependent equipment, and let them distribute the information to all the users. And we know it's worked because we have this product subscription service with over 50,000 subscribers right now. And when I look at that, as I do every month with the several hundred new subscribers, I will see lots of different farming groups signing up for the alerts and warnings. So we've got the word out there. I think we can do more.

Mr. MARSHALL. So are you able to predict those an hour before, a day before, a week before?

Mr. MURTAGH. So what they're most concerned about is impacts on the atmosphere typically associated with geomagnetic storms, so when we see the eruption on the sun, we can typically give them a 1- to 3-day notice that something's going to be coming up and something's going to be disturbing the ionosphere, stay tuned because they can——

Mr. MARSHALL. Yes.

Mr. MURTAGH [continuing]. Plan their farming for tomorrow and get a warning from us and say we'll postpone that activity until the next day.

Mr. MARSHALL. And typically they're knocked out for a day or two or——

Mr. MURTAGH. Sometimes just hours, but on the big storms—and sometimes we have an outbreak—October 2003 comes to mind—where this storm, we went down and out for about 2 weeks, so we like to get that information continuously flowing into the agricultural groups, knowing, be careful if you use your GPS and you're expecting precision navigation or precision measurements because it may not be there.

Mr. MARSHALL. OK. Admiral Lautenbacher, what are the ideal roles for the Federal Government, the academic community, and the commercial sector in developing strategies to address severe space weather events?

Adm. LAUTENBACHER. I think it's very important that we have an architecture that sets up the joining and melding of these great assets that we have in the United dates. When you look at the government, the government has to make the rule sets so that the playing field is fair. And so that needs to be—and government has—the only people that can do that. Nobody else can do that. The rest of it is competition.

Academia is needed for government investment in the research, as you just heard, and that has to go on, and that's mostly done in our academic world. So we are dependent upon that.

And when you get to the commercial sector, you have the ingenuity and the experience of working to provide very efficient solutions to the research that's been invented and the needs of the space production centers. And if we put that together in that way and have a comprehensive combination of those forces, we can do much better than we do today.

Mr. MARSHALL. OK. Yes, I yield back. Thank you.

Chairwoman FLETCHER. Thank you very much. I'd now like to recognize Ms. Horn for 5 minutes.

Chairwoman HORN. Thank you, Madam Chair. This is incredibly important, glad we're having this conversation. As I mentioned in my opening statement, I want to turn to a couple—more discussion, and this is a question for all of you, a couple of questions about the gaps so we can better understand as we address these issues. The bottom line I think is we have to do what's necessary to protect our space assets. We've covered many reasons from farming to our communications, our electrical grid, and our national security.

So in looking at these risks to our infrastructure, I'd like to hear from each of you briefly what are the biggest gaps in our space weather forecasting capabilities, and what we should prioritize to make the biggest impact in reducing these gaps.

Mr. MURTAGH. There are so many unfortunately. I refer to them as the holy grails when I talk to our colleagues in the science community. One is simply this. Again, I'll give you an example. It was October 17, 2003. I'm on the forecast desk and looking at the sun. There's no sunspots. We need sunspots typically if we're going to have big activity. I've got customers asking what is space weather going to look like for the next week. I say, well, pretty darn calm-looking right now.

One week later we had three Jupiter-sized sunspot clusters. That's about 10 times the diameter of Earth on the sun. These were intense Carrington-like very large complex sunspot groups. The bottom line is this. We have no real ability to predict that's going to happen. If we could only understand a little bit about when these sunspots are going to emerge, and when they do start growing, when are they going to stop growing because that happens sometimes, too. We'll have them grow in 1 day, 2 days later, and then it's gone, but it is a big, big limitation. People ask us what's going to happen a week or two from now. Well, we really don't know at solar minimum, not much sunspot activity, solar max, but we cannot forecast those sunspots.

And one last piece, when the sunspots do emerge and we know there's potential for big eruptions, 5 minutes prior to the eruption, we don't know it's about to occur. So there are significant limitations. And I limited my comments to the sun. I could share all the way down to Earth with some of the serious challenges we face.

Dr. FOX. So I would say, you know, NASA is really addressing a lot of these gaps by putting up the new missions. Parker Solar Probe of course brings to mind as now being the first mission to a star that is really going in and helping us to unlock exactly this area that Mr. Murtagh was just talking about, which is how do these sunspots, what is the structure of them, and the only way to really do that is to go and study them up close. And so we are certainly making big strides to close those gaps.

I do think that we need to do a continued effort to transition our scientific models into operational platforms, which we're working incredibly closely with our colleagues at NOAA to do that. We talked about the framework and the testbeds to really take advantage of all of the stuff that we are doing in the NASA Heliophysics Division and really taking benefit of all of that amazing science research and getting it into the operational community.

Adm. LAUTENBACHER. The gaps that we have today could leave us in very big trouble in the United States. A Carrington event today as opposed to when it actually occurred would be disastrous, worth maybe $20 billion just to think about trying to recover the power systems that we have, all of the wonderful television and radio and computer connections and our entire energy system would be devastated. And to even imagine—to try to recover that is huge. So these gaps are not meant—you know, a number of gaps cause that issue.

We really need to work on the plans that we built. And I've got right here a copy of the SPRWG study, which has illustrated what we need to do in here in terms of the type of measures we need to take, the type of instruments we need to have, and we need to get the money and the support to do this. Thank you.

Chairwoman HORN. Thank you all. I just have a few seconds left, so I'll keep this short, but I think it's an important piece to touch on, and that is determining the difference between space weather and artificial or manufactured events, especially in the area of our national security. How much are we able to distinguish between those? And because of time, Mr. Murtagh, I would just direct that to you. Where are we in that capability, and what do we need to do to address that big question?

Mr. MURTAGH. Well, certainly it's one of the reasons we really want to make sure we get our information and data out. We work globally. Space weather has a global effect, so when one of these big space weather events happen, we want everybody to know it is in fact a natural environment that's causing the problems. So it's just a key element in the process here is to make sure people have the situational awareness. And obviously the DOD has their own capabilities to sense when it's not natural, so——

Chairwoman HORN. Thank you. I yield back.

Chairwoman FLETCHER. Thank you. I'll now recognize Mr. Babin for 5 minutes.

Mr. BABIN. Thank you, Madam Chair. You all have already touched on some of this, but with advance warning, Mr. Murtagh, with advance warning, what can we do on Earth to prevent a major catastrophe such as an electric power outage? You can't really tell in advance. What can we do to harden our systems down here? We've been talking about this for years, and I'm not sure we've yet taken it seriously from a national security standpoint. Can you address that?

Mr. MURTAGH. Yes, I think the Federal Energy Regulatory Commission stepped in some years ago to essentially advise the industry that this was a real threat and then direct standards. So the power industry, there's essentially two pieces to it here. One is the engineering solution, so they are exploring opportunities to harden the various components of the grid, so a lot of work underway right now on them trying to do just that.

The second piece is the operational response, and that is essentially that we get the alerts and warnings out to them, and they understand what to do with information. So again, that's really an awful lot of work just in the past several months and years to address that threat. So we're coming at it at kind of a two-prong approach, the engineering solution and the operations response. But I think because government and FERC, the Federal Energy Regulatory Commission, did step in and mandate these activities, things are happening.

Mr. BABIN. That's good. I'm very glad to hear that. And, Dr. Fox, are astronomy and heliophysics the same thing, and if not, what are the differences and which discipline should lead to space weather activities as it pertains to research and operations?

Dr. FOX. So the sun is a star, as we all like to say, and so there's a lot of overlap between astronomy and heliophysics. But heliophysics is really focused on the study of our star, our sun, and its impact on Earth. Both, you know, high up and very close down to us, all the technology that we really rely on is—sort of lives in the heliophysics neighborhood. But it's extremely important as we move to look for exoplanets and habitability around other stars, you know, heliophysics and astro are very linked there because what you can learn about our star in our—kind of in our backyard is then applicable to other astrophysics systems. But heliophysics really is the science research arm of the national space weather program.

Mr. BABIN. Thank you very much, fascinating. And Admiral Lautenbacher, how important is space weather, just a general question, but how important is space weather to our national security?

Adm. LAUTENBACHER. It's a lot more important than most people think, I got to tell you. Yes. It's incredibly important. In the problems we would have with a natural attack if you want to call it that with the—with our power grids and our electronics that run the world today would just stall things——

Mr. BABIN. Yes.

Adm. LAUTENBACHER [continuing]. Where they are. We need to have a lot more people in all sectors understand what that means because we're talking about a whole society. We're not talking necessarily about one store or one powerplant. We're talking about months to try to get powerplants back online and all of the things that we use to control the manufacturing, our food production, all of the relationships we have between companies and governments and the basic items that are needed for life are absolutely in the mix on this. So we need to take this very seriously. We need to get more people involved. The private sector has a lot to offer and so do all the agencies. They need to be put together in these plans which have been put together with experts, and we need to fund them and support them.

Mr. BABIN. Yes, sir. Thank you very much. One more question, and this is for you Admiral. How is the space weather information collected by NOAA shared with the general public and the private sector, and how can NOAA better serve non-Federal organizations that may be interested in space weather forecasting information? Admiral?

Adm. LAUTENBACHER. Yes. I thought that was for someone else.

Mr. BABIN. OK. No. You want me to repeat it?

Adm. LAUTENBACHER. Please——

Mr. BABIN. Sure.

Adm. LAUTENBACHER [continuing]. Because I didn't hear the first part.

Mr. BABIN. How is the space weather information collected by NOAA, and how is it shared with the general public and the private sector, and how can NOAA better serve non-Federal organizations that may be interested in space weather forecasting information?

Adm. LAUTENBACHER. I got it.

Mr. BABIN. OK.

Adm. LAUTENBACHER. And why I checked out was you said NOAA. I was last head of NOAA in 2008.

Mr. BABIN. OK.

Adm. LAUTENBACHER. So I thought that would go to Bill. But anyway, that's OK. Because he's——

Mr. BABIN. Well, I'm out of time, so whoever wants to answer that can.

Adm. LAUTENBACHER. Yes, Bill, do you want to try it because you're here. I am not current. I'm exactly what NOAA is doing in all of the things. I can tell you what I'd like to have them do but I'm not current on that. Bill maybe more current than I am right now.

Mr. BABIN. I'm out of time so just very rapidly if you don't mind.

Mr. MURTAGH. Yes. Well, we have a policy in NOAA to make sure this data is made publicly freely available to all, so we have different systems, ground-based systems to bring down the space weather information, and we redistribute it. We process it and redistribute it and make it available, pretty much everything we do to everybody out there.

Mr. BABIN. Right. OK. Thank you. I yield back.

Chairwoman FLETCHER. Thank you. I'll now recognize Ms. Bonamici for 5 minutes.

Ms. BONAMICI. Thank you so much. Thank you to our witnesses for your testimony and your expertise. I noticed when Dr. Babin made his opening statement he made a comment about how space weather might not be at the top of the minds of our constituents. It didn't come up in any of my townhall meetings, but I think if you said to people what if there was something that would disrupt your power, affect flights, your GPS wouldn't work, I think they would all be very, very concerned.

And we know that space weather has the potential to affect our planet, our economy, everything so instantly. And as we continue to rely on infrastructure like electric power grids and aviation satellites and global navigation satellite systems, and as we promote greater exploration of space, I think we become more susceptible to the effects.

So last year when we held a hearing on space weather, it was revealed that the United States is probably decades behind the forecast capabilities for terrestrial weather predictions. And we don't have the capabilities to prepare ourselves before an event occurs. And when you look at the cost of preventing an impact, it's probably quite low compared to recovering from an event.

So, Mr. Murtagh, in your testimony you talked about the space weather scales and determining the relative severity of space weather storms. And last Congress I worked with Ranking Member Lucas on the *Weather Research and Forecasting Innovation Act*. Thank you, Admiral Lautenbacher, for your mention. We had extensive conversations in this Committee about how weather forecasts don't serve the needs of the public unless they're effectively communicated.

So following up actually on the conversation you were having with Dr. Babin, the stakes seem even higher for space weather events. So how does NOAA balance communicating the urgency of space weather events but also recognizing the level of uncertainty that persists in forecasting these events?

Mr. MURTAGH. So we absolutely prioritize getting the message into the hands of the right people first. It's a business where if we do all the right things, in other words we detect, we observe the incident, we predict it correctly, we get the information into the hands of the power grid operators, they take action and nothing happens because everything worked right. So we've got to get the information into the hands of the satellite operators, grid operators. That is our number one priority.

We do also recognize the fact that social media, while it's great in so many ways, it could be really hell during a space weather event.

Ms. BONAMICI. Right. Right.

Mr. MURTAGH. And so one of the things we do as quickly as we can is initiate—and we worked this through the Comms office at National Weather Service and NOAA is to initiate a media—not a press—it would be a press call and a media call, tele call. We'd bring in about 100-plus I think on the last time we activated that. And we try to get the messaging out. We try to use the mainstream media to get good information out there because all sorts of things are going to be said.

Ms. BONAMICI. Sure.

Mr. MURTAGH. And our website's going to have the information, but who's going to be running to SWPC, right?

Ms. BONAMICI. Right. Right. I think the last time I asked about risk management and event risk management, and, you know, there are vulnerabilities in those systems, as we know.

I want to ask Dr. Fox a question. What I really want to ask you is what's on your shirt, but I am going to ask you—is that the most important question of the hearing? Is it something related to space weather?

Dr. FOX. So it's Parker Solar Probe. And in my defense I'm giving an IAC (International Astronautical Congress) lecture at 6 p.m. on Parker Solar Probe.

Ms. BONAMICI. Perfect.

Dr. FOX. So I'm kind of dual dressed——

Ms. BONAMICI. Perfect.

Dr. FOX [continuing]. Today.

Ms. BONAMICI. That's perfect.

Dr. FOX. I apologize.

Ms. BONAMICI. Thank you. So, Dr. Fox, in your testimony you highlighted several key missions that will help map out the interconnected system and provide a holistic assessment of the sun's influence. So following up on the conversation about gaps in research, what do we need to fill them? I think Representative Horn asked about what the gaps were. How can Congress help fill those gaps? What are the best ways to do that?

Dr. FOX. So, I mean, I think one of the really nice things about being the Heliophysics Director is all the science that we do really does have a public purpose. You know, it really is easily translatable. There is a reason that we do it. It's really, really cool science, it's really great research, but there's always this human benefit because we are looking at the impact of our closest star on us here at Earth.

So we do continue to launch new missions. We are very thoughtful about the new missions that we select through our Explorer program and through some of our strategic programs, and we of course really, really do look to the National Academy. So as we move into our next decadal to be looking at better helping us to really, you know, put the science where it needs to be. And so really keeping the focus on the importance of space weather and the importance of heliophysics as a discipline is really critical.

Ms. BONAMICI. And in my last few seconds, is there agreement on where the gaps are among everyone here? Does everybody agree where the gaps are, and then we have to figure out how to fill them?

Dr. FOX. So I think probably any scientist will tell you the gap is in their favorite area of science, but, I mean, really understanding the star so really exactly what Mr. Murtagh said, you know, going in and understanding those sunspots, that's the key that, you know, understanding how they form and then better being able to say, oh, that one, I've seen that before, that one's going to do this tomorrow. And you really can only do that going in and really understanding the star.

Ms. BONAMICI. Thank you.

Mr. MURTAGH. And we do work very closely together.

Ms. BONAMICI. Perfect.

Dr. FOX. We do.

Ms. BONAMICI. My time is expired. Thank you. I yield back.

Chairwoman FLETCHER. Thank you. I'll now recognize Mr. Posey for 5 minutes.

Mr. POSEY. Thank you, Madam Chairs and Ranking Members, for holding this very important meeting. I think space weather is one of the most under-prioritized subjects that we have in Congress.

We heard from a panel previously that we missed a solar interruption, or CME that you call it, a couple years ago by 1 week on our orbit that would have knocked out all our satellites, killed all our power grids, and they couldn't even quantify the damage other than to say it would have been catastrophic.

There was a book written about a similar knocking out of our grid called *One Second After*. I don't know if any of you all have ever read that book before, but it's just frightening. And that was written from reports that Members of Congress have received on the EMP threat, same effect as we've had from those huge solar eruptions.

And so a question that I have for you is, you know, what plan does our government have in place if our satellites or spacecraft detected a geomagnetic storm headed right for us?

Mr. MURTAGH. So it would depend of course on which sector we're talking about. When a big event is coming, we're in touch with the satellite operators around the world, power grid operators, the aviation dispatchers, and they'll reroute the flights away from the poles and whatnot.

But the key right now, there's an effort underway within the Space Weather Operation and Research Mitigation Working Group at OSTP (Office of Science and Technology Policy) to define benchmarks where we want to say how big is big so we can protect against that level? Because that's kind of where we're at right now, the step is we've got to recognize that number, that value, and then work with industry to take the appropriate steps.

It's happening already to some degree obviously with the power grid. We have given them a number, the volts per kilometer. If we get to this value, you need to assess will you survive. They are doing that right now. They'll understand which equipment is vulnerable and then take action to protect it. So hopefully in the coming not-too-distant future, we get to a place where we think that they can withstand almost Carrington-type event. So we're working on getting there because we know a lot about this storm. We didn't 20 years ago. We do now, and we're working toward mitigating, hardening the system if you will, to withstand one of these big events.

Mr. POSEY. Yes, I've noticed industry hasn't had much interest in hardening. Industry is interested in bottom-line and bonuses for the next fiscal year.

Mr. MURTAGH. Yes.

Mr. POSEY. What do you think we should do to overcome that?

Mr. MURTAGH. Well, I think that—and I mentioned this already—FERC (Federal Energy Regulatory Commission) stepping in and telling them, directing them to do this assessment, what was critical. And where it's difficult is not in the high-latitude States. States that border Canada recognize this threat because they experience it quite regularly. It's the mid-latitude States and the lower-latitude. Those folks could have been there for 40 years working that system and they'll say, why am I worried about this, I've never seen this before? We haven't had an 1859 event since 1859.

Mr. POSEY. Right.

Mr. MURTAGH. So the only way really to get them motivated to move and do the right thing is largely I feel with FERC stepping in and——

Mr. POSEY. Yes. Besides the outages that caused Quebec to lose their power for about 9 hours, what other ones are we aware of? Are there a bunch of other minor ones?

Mr. MURTAGH. Yes, there was—so actually—yes, there was—we go back to 1859 for that big event. In 1921 there was a paper published just last month suggesting that the 1921 storm might have been as big as Carrington, and that 1921 storm was the one that caused the fires in railway—they call it the Railway Storm because it actually caused fires in downtown Manhattan in the railway station due to the induced current. So there was that one and the one you mentioned in July 2012, which was a near miss. So there are three or four Carrington-class events. There has been many, many others. The Bastille Day events that Dr. Fox just whispered in my ear was a big one that occurred in 2000. There was the 2003 event that brought the grid down in Malmo, Sweden, and damaged many transformers in the Eskom network in the South Africa. So I could go on and on with a list of these things.

Mr. POSEY. Obviously, the research is important to the survival of our species. You know, what effect do you think would have globally if the 1859 event happened today?

Mr. MURTAGH. Well, I think it would be significant in many ways obviously. Again, depending on which sector—a huge part of this whole national strategy and action plan that was referenced already is to—one of the first big part of that is assess the vulnerability of our critical infrastructure. We're in the process of doing that now. To get to a point where we can accurately answer your question is just what would happen if we got this level of storming? We have still a lot of work to do to understand that vulnerability.

Mr. POSEY. OK. Thank you. So we really don't know.

And, Madam Chair, thank you for letting him answer the question.

Chairwoman FLETCHER. Thank you, Mr. Posey. I'll now recognize Mr. Tonko for 5 minutes.

Mr. TONKO. Thank you, Chairwoman Fletcher, and thank you, Chairwoman Horn, both of you for holding this hearing, and thank you for the witnesses for joining us today.

Space weather may seem like a far-off topic, but it has many implications, as we all know, for our lives on Earth. Our ability to monitor and predict space weather events hinges on our continued support for research, for the workforce, and for innovative collaboration.

This past August, the new NOAA USGS model for electric power grid operators went live. This map illustrates regional electric field levels in the U.S. using near-real-time data to show the extent of space weather impact that could affect the power grid.

So, Mr. Murtagh, since its launch, to what extent has the map been useful to grid operators in mitigating the impacts of space weather on critical infrastructure?

Mr. MURTAGH. Not much use yet just because we haven't had anything happen since its release. However, we think it's a huge step forward, and I'll tell you why. When SWPC issues a warning on the scales we talked about, G4—it's a geomagnetic storm, emphasis on geo, meaning it's an Earth storm. But the folks in this Nation that operate the grid want to know is what about where I live? What's going to happen? What's going to happen to greater New York City versus San Francisco?

And this new geo-electric field is going to provide that kind of information, not on the magnetic field but the actual electric field that develops so they can calculate the current that's going to be introduced into their system, that D.C. current that they don't want to have to deal with this product is going to provide us. So we envision this thing—this model running operationally 24/7 in grid centers around this country.

Mr. TONKO. And in regard to the improvements there, what outreach has occurred to ensure that stakeholders are aware of the development of the opportunity?

Mr. MURTAGH. So, fortunately, there's the North American Electrical Reliability Corporation in Atlanta that are essentially responsible for enforcing the standards that came from FERC. Within that group, which involves all of industry, there is a GMD, a geomagnetic disturbance task force. We are a big part of that. Every meeting, which is about quarterly, we're in there updating them with this information and advising them when it's available, and when it is available, we let them know when it was distributed to everyone so we know it went to every grid, electric power generation and transmission entity across this country and Canada.

Mr. TONKO. Thank you. And to both you, Mr. Murtagh and Admiral Lautenbacher, what economic and social science research exists that might help us understand the potential impacts on different sectors of our economy in regard to the economic and social research being done?

Mr. MURTAGH. Shall I? There was—I think it was referenced once already, NOAA sponsored a report recently. It's online. It's published a couple years ago. The Abt Associates was the company that did it, which is essentially—we asked them to give us a sense of the potential economic impact on the various sectors from an extreme space weather event.

So that document was released, and someone referenced a $20 billion impact. That was a number associated with a grid outage, a 9-hour outage in a relatively small area in this country due to a geomagnetic storm. So that document has helped as a good reference, a good reference material for us to use.

Mr. TONKO. OK. Anything that you want to add to that, Admiral?

Adm. LAUTENBACHER. No, that's the best thing that I know of that we have out there right now.

Mr. TONKO. OK. And with the space weather effects that range from insignificant to highly disruptive to our communication systems, with the public and business involvement, should they prepare for such events if they—are they informed in a way to know how to respond to different events? And how often do different kinds of space weather events occur?

Mr. MURTAGH. So on the NOAA space weather scales, it's a question that's so often asked. How often do they occur? So we did include it on there. And that 1 through 5 where 5 is an extreme event on a radiation storm, the S scale, we haven't had one of them in 30 years. We started taking measurements in 1974. We haven't had one yet. On the G5 level, extreme geomagnetic storm, typically we'll get one or two per cycle. I think the last one was in 2003.

Industry and customers are so wide-ranging now, some of them quite sophisticated and understand this stuff like satellite operators. Many others, not so much. Airlines would be a good example. So we do maintain close communications with those folks to make sure that they understand what they're getting when they get it.

Mr. TONKO. OK. My time is now exhausted, so I will yield back.

Chairwoman FLETCHER. Thank you very much. I'll now recognize Mr. Murphy for 5 minutes.

Mr. MURPHY. Thank you, Madam Chair. I just want to say thank you to the presenters. Your expertise and dedication to this field is exemplary, and it's obvious.

You know, one person made a comment a few minutes ago, I think it was Mr. Murtagh, about individual weather. That's what most people care about. They want to look outside and see if it can have a picnic or go to a ballgame. But it's under your responsibility, it's under our responsibility really to look at the bigger global picture. And so I thank you for that. It's an important thing that doesn't have partisan politics in its back pocket. It doesn't have national politics in its back pocket because the Earth is one place, and it's affected globally by events that occur in the sun. So, again, thank you for your dedication. It's really important really for us as a species if it is.

Just a couple questions. I'll be a lot more granular. I live down on the East Coast of North Carolina. My district probably has more coastline than anybody else in North Carolina, so I want a crack here at your brains on seeing if you can help me. Is there anything that we have as far as space weather prediction? You know, we have these things called hurricanes, and we don't like them in North Carolina, but they tend to come right to us. And so I didn't know if there's anything that you guys have, you know, up your sleeve that help us in the future to be able to predict the intensity, predict the path, predict the rainfall amounts that we can use to better gauge how these will affect us.

Mr. MURTAGH. Yes. And there's been a term we've been using at the operation center. We call it the money chart, and that's what you're looking for is something that makes sense to people. But is it to identify when GPS may be having problems or when there's a potential grid problem? We are absolutely focusing—and I mentioned it already with the geoelectric field model—focusing on trying to capture that key piece, where will the impacts be felt? We should be past that point where we're advising the whole world something's going to happen, it's going to hit somewhere, maybe in South Africa, maybe in Scandinavia, or maybe in New York City. We have got to be able to identify and then help the folks in North Carolina understand when space weather might affect them. So we are getting there.

I have introduced a new suite of models on the Earth modeling system that's helping us just drill down and start—we're years away, but we have to start somewhere to get to that point where we can do just as you ask.

Mr. MURPHY. Excellent. Thank you. Just one other question. You know, the United States, we seem to be leading in this regard. This is a global issue. It's a global phenomenon. How much funding does the United States put in compared to other nations? And where are we in trying to get our global partners to jump on the bandwagon and really participate in this as an earthly event?

Dr. FOX. So we have very close partnerships with many of our overseas colleagues. We actually sort of work together on a lot of the missions. For example, solar orbiter, which is an ESA mission, has a couple of NASA instruments but NASA is actually launching it for them. We are also in—talking to them about a possibility of an L5 mission, so Mr. Murtagh mentioned the L1 point, which is a million miles away. L5 is kind of off to the side, so it lets you look at those sunspots coming round before they actually get to you. And so we're actually talking very closely with them about that.

We've talked to many of our sister agencies in other countries because really, as you note, space weather is a global problem. It doesn't just hit one place. You may be unlucky, and we happen to be at the midnight sector, which is that kind of worst place to be as things come rushing down on the night side, but until we can really say it's going to be here at this time and this is the country that's in that little window, it's really a global problem. So we work very, very, very closely with all of our sister agencies to really make this a global solution.

Mr. MURPHY. Excellent. Thank you, Madam Chair. I yield back my time.

Chairwoman FLETCHER. Thank you very much. I now recognize Mr. Crist for 5 minutes.

Mr. CRIST. Thank you, Madam Chair, and thank both the Chairs for convening this hearing. I appreciate that very much.

It's sort of an overarching question to anybody who wants to answer it, and thank you all for being here by the way. What's the most dangerous aspect for humans from space weather?

Dr. FOX. So that really depends honestly on the system that you particularly care about. For the human body, for our astronauts, that's why we really have to watch the space radiation, and we've put a lot of investment and a lot of effort. NASA's number-one priority is the safety of our astronauts.

Down here on Earth obviously we don't have to worry about that, but airline passengers, we watch the radiation for those. Power grids we've already talked about. That becomes very critical if suddenly it's a life-and-death situation where you're relying on that power grid to be up. So it really depends a little bit on your perspective, but for NASA, certainly it's the radiation effects on our astronauts.

Mr. MURTAGH. If I could just add to that, the Committee might be interested to know that within the United Nations there's the International Civil Aviation Organization (ICAO) who has been working on this issue for over a decade now. And coming up next month, hot off the press will be a new suite of space weather services that will be provided for global aviation, space weather services. And the ICAO group have identified three centers for the provision of these services, and the United States is one of the three. The threat of course is communications, navigation, but also, as Dr. Fox mentioned, radiation exposure. When you fly over the poles, there is increased radiation that can cause some problems.

Mr. CRIST. Great. Admiral?

Adm. LAUTENBACHER. I mentioned that there is also part of the commercial sector that produces sensors that people can wear and maintain and get immediate connection with the ground to find out whether they're getting exposure that could be dangerous and how they can change the mission and that sort of thing. So these inventions that are out there now are going to be very helpful to the aviation world.

Mr. CRIST. Thank you very much. Thank you all. So radiation is the greatest concern it sounds like?

Mr. MURTAGH. Just from human exposure. And obviously——

Mr. CRIST. Indeed.

Mr. MURTAGH [continuing]. Losing electric power over a wide area for a long length of time would be a big, big concern.

Mr. CRIST. Certainly. What is the cause of the radiation in space? Is it solar spots or—yes?

Dr. FOX. So the increased radiation usually is because of those sunspots that we call it a flare where you see that bright flash of light and it accelerates particles at about half the speed of light, so they take 8 minutes for light to travel from the sun to the Earth.

It's about 15 to 20 to 30 minutes, those particles will start coming in.

However, we live with our own radiation environment around us. We have the Van Allen radiation belts, the two intense radiation belts that kind of encircle the equator, and we have a lot of spacecraft, space assets that actually have to travel through these belts. And sometimes when we get these big events, these belts can grow both in size and also in intensity, and so that can have a very big impact on the assets that maybe they're not actually supposed to be in the radiation belts and suddenly that radiation belt kind of grows and engulfs that spacecraft.

Mr. CRIST. Is it safe to say generally that our atmosphere protects humans on Earth for the most part from any radiation from the sun?

Dr. FOX. Yes, we're very lucky from that. Yes.

Mr. CRIST. I would say. And I guess probably my last question, Dr. Fox, to you, in your testimony you note the potential for the Artemis program to further our knowledge of space weather and space radiation. It is my understanding that this is because the Moon is well outside of the Earth's protective magnetic field. What challenges or opportunities does the orbit of the lunar gateway present for heliophysics, particularly as it relates to space weather?

Dr. FOX. So definitely lots and lots of opportunities, as you note. The Moon is sometimes protected when it's behind the Earth. It's in our magnetosphere, so it's protected, but there are a lot of times when the Moon is actually out in what we call the pristine solar wind, so this continually expanding atmosphere of the corona coming out and engulfing us. And so we really look forward to being able to further our knowledge of what is in this solar wind and then apply that to our Artemis program as we go forward to the Moon and Mars and beyond.

Mr. CRIST. Great. Thank you, all three of you, very much. Thank you, Madam Chairs.

Chairwoman FLETCHER. Thank you. I'll now recognize Mr. Perlmutter for 5 minutes.

Mr. PERLMUTTER. Thanks, Madam Chair. And, Bill, good to see you.

Mr. MURTAGH. Good to see you.

Mr. PERLMUTTER. Thank you all very much for your testimony today. I'll be pretty brief, just a quick statement and then a couple questions. So thank you for convening this hearing. I've been interested in space weather for some time now, and I'm excited the Committee is really looking at this closely.

Colorado, Mr. Murtagh, has some of the best minds, laboratories, and research institutions on space weather in the country. We have institutions like CU Boulder and the National Center for Atmospheric Research, as well as NOAA's Space Weather Prediction Center, among others. And that's why Cory Gardner, a Senator from Colorado, is working with Gary Peters, a Senator from Michigan, on the *Space Weather Research and Forecasting Act* in the Senate, and that's why we've been encouraging the Science Committee to take up that legislation to help the academic community and the commercial sector best contribute and participate in our space weather enterprise, so to work with NOAA through this whole process and make sure we don't have silos. And, you know, over the last couple years I can see that those silos have been really disappearing, which I just want to applaud you all so that we're not all just sort of not talking to each other.

And just since I was introduced to this subject, clearly the communication lines between the academics, the government, and the commercial sector have just improved magnificently.

The Senate Commerce Committee passed an updated version of this legislation in April, and since that time, I've been working with Mo Brooks to update that legislation with some additional provisions and move us closer to passing the bill into law. Our overarching goal through this legislation is to advance space weather research and forecasting enterprise, help solidify the swim lanes, who's actually doing what, but then really continue a robust communication between the different groups.

I want to thank Mr. Brooks for his partnership on this issue and the committee staff for their expertise as we've been drafting this bill. We hope to release the text of the bill next week to get additional feedback from all of you, our colleagues, the agencies, and academia and the commercial sector.

So, Admiral, I'd like to start with you. I see Mr. Murtagh not on a regular basis but from time to time, and you know, since I'm not too far away from the Space Weather Center. So my question to you is, what things do you think need to be done to improve the overall communication between the academic community, NOAA, and the commercial sector? And then I'll ask you about the military in just a second.

Adm. LAUTENBACHER. We have to build a more robust system that combines what I would say meetings, kind of protocols to deal with. And we get used to the fact that we need to work together across—from—and the civilian side is maybe a little more fractured because there are different companies, but we do have, you know, organizations that bring together companies and can work with government agencies. It's very hard to take a government agency and work with a group of companies. And that's too hard, I'm not going to work on this one today.

In this area, we really need to stress ourselves and get to the point where we have those mechanisms. The mechanisms allow a phone call to be picked up and talk directly and so that we can do rapid reaction, moving of the data, moving of the issues. The commercial sector is in good shape in a way because it has folks all the way from basic research all the way up to emergency management to help in situations. So we would like to be involved in those kinds of conversations and the bill could help us set up something that would be, I think, more robust than we have today. Thank you.

Mr. PERLMUTTER. Dr. Fox, what are your thoughts?

Dr. FOX. So I, first of all, would recognize the tremendous efforts that have really helped us from the National Space Weather Strategy and Action Plan, and they're really providing a forum for us to work really, really well together on really tough problems. I mean, as you can probably note, NOAA and NASA are working very, very closely together on the space weather piece itself, taking all of our great research and then making sure that we really are transitioning it. So I really think that has just been a tremendous benefit.

And I'll also note that, you know, at NASA we've really embraced this idea of sort of rideshare programs. There is now a rideshare policy that we have of making sure if there's something launching that we look for other opportunities to take more mass to space, get more science in space. And that of course includes our commercial partners also. And so under the Artemis program we really are exploring even more the commercial side.

And then I'll just throw in—I know that we're out of time—but from our decadal survey, we were asked to do this DRIVE (Diversity, Realize, Integrate, Venture, Educate) initiative. And one of the big things was the science centers, and so that really does just provide this amazing forum for academia, government, industry all working together. We're excited. We got 39 proposals. It's a nightmare to try and review them, but it's a product of our own success, so we're happy.

Mr. PERLMUTTER. All right, thank you. And, Bill, I'll ask you my question when we're on the flight home.

Mr. MURTAGH. All right.

Mr. PERLMUTTER. I'll see you.

Chairwoman FLETCHER. Thank you. Thank you. Well, before we bring the hearing to a close, I want to thank all of you for your testimony here today. I think it was really important, and I'm so glad that we were able to have this hearing.

The record of the hearing will remain open for 2 weeks for additional statements from the Members and for any additional questions that they may ask of you. And so I look forward to seeing your additional answers or should more questions be sent, and I think I saw my colleague Ms. Horn jotting one down, so I think you all can all expect at least one.

But for now, you all are excused, and the hearing is closed. Thank you so much.

[Whereupon, at 4:11 p.m., the Subcommittees were adjourned.]

# Appendix

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## Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

*Responses by Mr. Bill Murtagh*

**Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities**
House Committee on Science, Space and Technology
Subcommittees on Environment, and Space and Aeronautics
Wednesday, October 23, 2019

*Questions for the Record to Mr. Bill Murtagh*

**Submitted by Chairwoman Eddie Bernice Johnson**

1. **Mr. Murtagh, in your written testimony you mention that ground-based magnetic field data collected through the USGS Geomagnetism Program are incorporated into NOAA's geomagnetic storm warnings and alerts and help distinguish the intensity of geomagnetic storms.**

**1a. Will you please elaborate on NOAA's and USGS's relative roles in this collaboration with the USGS Geomagnetism Program? What are avenues for future collaboration with the Geomagnetism program?**

**Answer 1a:** The USGS Geomagnetism Program, through the 24/7 magnetic field observations provided by the USGS magnetometers, provides critical data used by NOAA to produce geomagnetic storm warnings and alerts. NOAA maintains a very close working relationship with the USGS Geomagnetism Program, and we are collaborating on developing the next phase of geomagnetic storm products used to protect infrastructure vital to national security and the Nation's economy, including the electric power grid and satellite systems. USGS procures the observing instruments and distributes the observations; NOAA receives the data and integrates it with other information to produce warning and alert products.

**1b. What is the importance of this program, including of its magnetotelluric survey?**

**Answer 1b:** As mentioned above, the USGS Geomagnetism Program plays an integral role in NOAA's responsibility to provide space weather products and services to meet the needs of the Nation. The magnetotelluric (MT) surveys are one example of this and are critical to develop the next improvements of the NOAA-USGS Geoelectric Field model, mentioned in part c) below, which estimates regional geoelectric field levels on a geographic grid over the contiguous U.S. MT measurements are essential for real-time mapping of the geoelectric field, which provides grid operators the information they need to help mitigate the effects of geomagnetic storms. To allow for the improvements to the Geoelectric Field model, the completion of the MT surveys is required. Currently, the MT surveys are complete for two thirds of the contiguous United States.

**1c. You also note that NOAA and USGS have released a new Geoelectric Field model this past September. The model characterizes the space weather impact to the U.S. power grid and helps operators in mitigating impacts to critical infrastructure. Can you elaborate on how NOAA and USGS worked together on this model, and**

**on the ongoing work to improve the model? How has it been received by power industry stakeholders?**

**Answer 1c:** The new NOAA-USGS Geoelectric Field model produces the first ever Geoelectric Field map product. The USGS are managing completion of the national-scale MT survey, processing the data, and incorporating the measurements into the existing MT database. The USGS develops surface impedance maps needed for estimation of geoelectric fields. NOAA then takes the impedance maps and incorporates real-time USGS magnetic field observations to produce the real-time geoelectric field model. Power grid operators have described the new Geoelectric Field product as “exactly what was needed” and they are now developing tailored products and tools for their grid control rooms. USGS and NOAA are working to further develop the model with up-to-date Earth-response functions that incorporate the full effects of the 3D Earth conductivity, which relies on the MT surveys (see answer b).

**Submitted by Subcommittee on Space and Aeronautics Chairwoman Kendra Horn**

2. **In response to my question on gaps in our space weather forecasting capabilities, you noted that "there are so many unfortunately," that "I limited my comments to the Sun," and that "I could share all the way down to Earth with some of the serious challenges we face." Is there a full identification of the gaps in our space weather forecasting capabilities beyond the ones you and Dr. Fox highlighted in response to my question? If so, please provide it for the record. If not, what process do you recommend for identifying the complete set of gaps?**

**Answer 2:** Yes -- the gaps in space weather forecasting capabilities are addressed in the 2015 roadmap – Understanding space weather to shield society: A global road map for 2015–2025 commissioned by the Committee on Space Research (COSPAR) and the International Living with a Star Program (ILWS)[1]. In 2015, the COSPAR and ILWS commissioned the development of this global roadmap for space weather. The roadmap prioritizes scientific focus areas and research infrastructure that are needed to advance the understanding and prediction of space weather to mitigate effects on critical infrastructure. Additionally, the Space Weather Operations, Research, and Mitigation (SWORM) Interagency Working Group is currently working on an updated set of research priorities in response to the National Space Weather Strategy and Action Plan.

3. **Electric currents from magnetic storms can appear in oil and gas pipelines, causing early corrosion. Are you aware of any companies that take this risk into consideration when designing pipelines?**

[1] https://www.sciencedirect.com/science/article/pii/S0273117715002252?via%3Dihub

**Answer 3:** Yes, pipeline companies do consider geomagnetically induced currents (GIC) when designing pipelines. It is our understanding that all major companies engineer their pipelines to mitigate GIC.

4. **What ground-based observations does the Space Weather Prediction Center (SWPC) use in its forecasts? How do these ground-based observations complement the in-orbit observations?**

**Answer 4:** The Space Weather Prediction Center (SWPC) uses many ground-based observations in its forecasting process. They include:

- Ground magnetometers: Real-time ground-level magnetometer data are used as summary measures of geomagnetic storm intensity and for identification of geomagnetic storm commencement, initial, and main phases. Ground magnetometers are used in tandem with a space-based coronagraph and in-orbit spacecrafts (Deep Space Climate Observatory/DSCOVR and/or Advanced Composition Explorer/ACE) at the Lagrangian 1 (L1) orbit to issue Geomagnetic Storm Watches, Warnings, and/or Alerts.

- Neutron Monitors: Monitors detect neutrons at ground level for: nuclear threats and treaty verification, measuring soil and snow moisture content, and solar radiation alerts for aircraft crew and passengers. There are approximately 45 operating neutron monitoring stations around the globe. SWPC uses in-orbit NOAA Geostationary Operational Environmental Satellite (GOES) systems data to produce solar 'Radiation Storm' warnings. Neutron monitor data are used in models to provide additional details necessary to assess the radiation exposure from solar radiation storms to passengers and crew at conventional aircraft altitudes.

- US Air Force F Solar Electro-Optical Network (SEON): SEON consists of the six observatories that contain one or both of the following: the Solar Optical Observing Network (SOON) and/or the Radio Solar Telescope Network (RSTN). The SOON provides key information on sunspot activity that is not available from our operationally dedicated space-based satellites. RSTN is the sole source for most solar radio burst information. SWPC uses SOON data to monitor sunspot development and evolution and to monitor eruptive activity on the Sun. The RSTN data provides important information on solar radio bursts that have the potential to interfere with GPS, satellite communications, and radar systems.

- Global Oscillations Network Group (GONG): The GONG is a set of six solar observing instruments located at sites around the world providing data critical to SWPC's solar wind model, which provides advanced warning of Earth-directed coronal mass ejections that cause geomagnetic storms. GONG provides SWPC with magnetic field images used as input to operational models of the changing heliospheric environment throughout the inner solar system; full disk images of the chromosphere used to detect and characterize flare and other eruptive activity; and helioseismic images of activity on the far side of the Sun. GONG is the sole source of operationally dedicated imagery used for detecting and assessing sunspot development on the far side of the sun. GONG is also the sole source of primary data driving the operational, high-resolution solar magnetic field data that in turn drives operational models at SWPC.

- Ground-based total electron content (TEC): TEC measurements from GPS receivers provide critical data on the ionosphere needed to assess impacts on communication, navigation, and surveillance assets in the national defense and civilian sectors. TEC measurements from GPS receivers, combined with the radio occultation (RO) data provided by the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)-2 satellites (launched in June 2019) will contribute greatly to our understanding and prediction of ionospheric disturbances.

**5. Dr. Fox's prepared testimony highlighted NASA's current efforts to work with NOAA to "develop a shared framework for research to operations." Could you elaborate on what the shared framework will involve?**

**Answer 5:** There are two key activities underway to develop a formal framework to incorporate research-to-operations-to-research (R2O2R) contributions from government, industry, and academic partners:

(1) NASA recently initiated the Space Weather Science Application (SWxSA) element, which is led by NASA and includes NOAA and other science agencies. The SWxSA program specifically focuses on investigations that will advance understanding of space weather with an “operations’” perspective, focusing on more accurate predictions with longer lead time and assessing processes that can be used for feeding the advancement of research into operations.

(2) NOAA and NASA are developing a space weather R2O2R framework that will foster collaboration between researchers and space weather forecasters to test and evaluate emerging science that may contribute to operations. Once developed and implemented, the framework envisions a testbed that would facilitate the transition of new research into operations, enable the improvement and maintenance of existing operational models, and provide feedback to research on where improvements are needed in modeling capabilities.

**5a. How are the Space Weather Prediction Center's operational challenges informing the space weather research priorities at NASA, NSF, and the broader academic Community?**

**Answer 5a:** A concerted cross-agency effort to strengthen the pipeline from research to operational capabilities began in January 2018 with the first Coordinated Interagency Space Weather Applied Research Funding opportunity. There have been three additional funding opportunities announced since then, all promoting space weather operations-to-research activities focused on SWPC’s operational challenges. This was followed by another important effort in November 2018 with the signing of the Tri-Agency NASA, NOAA, NSF Memorandum of Understanding focused on applied research for space weather, with forecasting identified as a clearly stated goal. The focus of each annual R2O2R research opportunity is jointly determined by NOAA, NASA, and NSF, and managed by NASA, as called for in the Tri-Agency MOU {see answer 7 below} .NOAA, working jointly with NASA, NSF, and the DOD, hosts the annual Space Weather Workshop in Boulder, CO. These workshops bring industry, academia, and government agencies together to focus on the highest priority needs for operational services that can guide future research and new high-value capabilities that can be transitioned into operations.

**5b. Are we doing as well as we could to ensure that there is a robust operations-to-research Activity?**

**Answer 5b:**

NOAA and NASA are currently developing a formal framework that will incorporate R2O2R contributions from government, industry, and academic partners to ensure there are no gaps between agency programs when it comes to space weather research transitioning into operations.

**5c. What types of assessments or reviews do NOAA or other partners conduct of the research-to-operations and operations-to-research processes?**

**Answer 5c:** An R2O2R workshop was held in Boulder, Colorado, in August 2016 to assess the current R2O2R processes, and to explore options and gather input from academia, private enterprise, and space weather customers. The workshop, hosted by NOAA, USAF, NASA, and NSF, produced a summary of ideas to improve the R2O2R processes. In January 2017, to ensure maximum reach, NOAA posted the results of this workshop on the Federal Register – "Notice of Availability of White Paper on Improving the Space Weather Forecasting Research to Operations (R2O)—Operations to Research (O2R) Capability and request for public comment." The feedback and the contents of the workshop report produced valuable input, which was then incorporated into a recent space weather testbed initiative.

**6. To what extent do we understand, and can we reasonably estimate, the risk and the potential economic and societal impacts of the range of possible space weather events, such as those described in the NOAA Space Weather Scales?**

**Answer 6:** In October 2017, in response to an action in the 2015 National Space Weather Action Plan, Abt Associates, under contract with NOAA, released a report titled "Social and Economic Impacts of Space Weather in the United States."[2] This report focused on space weather impacts across various technological sectors including electric power and satellites.

[2] https://www.weather.gov/media/news/SpaceWeatherEconomicImpactsReportOct-2017.pdf

The report indicated that a power outage associated with a geomagnetic storm could cost the Nation ~$20 billion for a 9-hour event. The report also presented moderate and extreme space weather event scenarios for the U.S. satellite industry and estimated costs at ~$200 million to ~$2 billion and ~$2 billion to ~$80 billion, respectively. This accounted for both lost asset values and potential losses in satellite revenue from a single space weather event. Economic impact analysis of space weather continues to be an area of active research as we learn more about space weather effects.

**6a: What are the best estimates of the risk and potential impacts available today?**

**Answer 6a:** Extreme space weather events occur at a relatively low-frequency; however, a number of estimates for the probability of an extreme geomagnetic event occurring within the next 10 years is approximately 10%.[3] There are two major consequences associated with geomagnetic storm impacts to the bulk power system: 1) damage to bulk power system assets, typically associated with transformers; and 2) loss of reactive power support, which could lead to voltage instability and power system collapse. The 2017 paper mentioned above assumes an outage due to voltage instability. Physical damage to hardware is a hotly debated issue, and efforts are underway to assess the true vulnerability of the transformer fleet. A scenario with significant transformer damage is considerably more alarming than a blackout related to voltage instability. There are long lead times to replace transformers, in the order of months (from customer order to transformer delivery), further exacerbated by limited domestic manufacturing capacity.[4] Reports on an outage associated with damaged transformers indicate costs to the Nation in excess of $1 trillion.[5]

[3] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016SW001470
[4] https://www.energy.gov/sites/prod/files/2014/04/f15/LPTStudyUpdate-040914.pdf
[5] https://www.nat-hazards-earth-syst-sci.net/14/2749/2014/nhess-14-2749-2014.pdf
https://www.aer.com/siteassets/solar_storm_risk_to_the_north_american_electric_grid_0.pdf

**Submitted by Subcommittee on Space and Aeronautics Ranking Member Brian Babin**

**1a. With advanced warning, what can we do on Earth to prevent a major catastrophe, such as an electric power outage?**

**Answer 1a:** Many power companies have established procedures to mitigate the impact of a geomagnetic storm. These include: re-dispatching and reducing large power transfer across critical corridors; canceling/postponing scheduled maintenance on critical equipment (e.g., capacitor banks); adjusting the topology of the system to reduce GIC flows in critical areas in the system; and initiating forced cooling in transformers. These are just some of the actions the grid operators will take when they receive advance warning of a geomagnetic storm.

**1b. Who is working with communities such as power utilities to ensure they receive and understand forecasts and warnings?**

**Answer 1b:** For the electric utilities, Space Weather Prediction Center (SWPC) staff coordinate with USGS and private sector companies working closely with the North American Electric Reliability Corporation (NERC). NERC is the electric reliability organization for North America and the international regulatory authority whose mission is to assure the reduction of risks to the reliability and security of the grid. Since 2012, NERC has convened the Geomagnetic Disturbance Task Force (GMDTF), of which SWPC and USGS have been members since its inception. SWPC has provided numerous presentations and tutorials and contributed to many of the NERC reports distributed to industry. In recent years, private sector service providers have also made important contributions to the NERC GMD activities. SWPC also works closely with aviation and other sectors to ensure they receive and understand forecasts and warnings.

**1c. Do you believe the current system is adequate or should we do more?**

**Answer 1c:** In terms of reaching users, current dissemination systems are adequate, but will need to change in the future as technology, understanding, and products improve to meet user demands. Communication bandwidth for disseminating our information has increased. Our dissemination capability has built-in redundancy within National Weather Service InteractiveNWS (iNWS) itself and through other methods of reaching users including email notifications and phone calls, which provide additional ways to receive information.

**1d. How is the space weather information collected by NOAA shared with the general public and the private sector?**

**Answer 1d:** NOAA collects and freely distributes all of its real-time space weather information via the SWPC website. NOAA's National Centers for Environmental Information (NCEI) are responsible for the archival and access of solar and space environmental data and derived products collected by NOAA's observing systems. Derived products, e.g., warnings and alerts, are provided via the e-mail based Product Subscription Service and through iNWS e-mails, text messaging, and mobile-enabled webpages. During large space weather events, SWPC will notify critical customers (e.g., electric power grid reliability centers, NASA Mission Control) via phone call.

2. **Given your expertise, are there ground based systems that can improve predictability of space weather events or are there some in the research pipeline? What are they, where are they located and who funds them?**

**Answer 2:** Yes. While not a NOAA project, the National Center for Atmospheric Research is developing the ground-based Coronal Solar Magnetism Observatory (COSMO), which has the potential to provide important information to improve our understanding of magnetic fields in the solar corona. COSMO would include the capability to monitor the global-scale magnetic fields of the Sun's corona and throughout the solar disk, which could provide important information for the next-generation space weather models. Its siting remains an unresolved issue.

3. **This Committee authored the Weather Research and Forecasting Innovation Act of 2017 that directed NOAA to procure commercial weather data. In 2017, the Air Force established a pilot program to evaluate whether commercial providers could provide valuable space weather data. Has NOAA considered lessons learned from the Air Force pilot program? Should NOAA implement a commercial space weather data buy program?**

**Answer 3:** NOAA and the Air Force have been sharing lessons learned from the directives that Congress has given to both our agencies to evaluate the utility of commercial providers to meet operational data needs. NOAA also believes that it currently has sufficient authorities to implement a commercial space weather data buy program.

4. **Would a commercial weather data buy be subject to World Meteorological Organization's Resolution 40 (WMO-40) that requires all signatories to freely share weather data? If so, does this underline any potential commercial space weather business models? If WMO-40 were to pertain to space weather data, would this forever cement the U.S. taxpayer subsidizing foreign space weather capabilities? Does WMO-40 pertain to the observation of all remote sensing? If not, how does the U.S. government determine where to draw the line?**

**Answer 4:** The data sets that are required to be shared on an unrestricted basis to World Meteorological Organization (WMO) Members, deemed “essential to support WMO Programmes,” are listed under WMO Resolution 40, Annex 1. NOAA interprets “a commercial weather data buy” in this instance to mean purchased data. The only data NOAA purchases operationally that are classified as “essential” under WMO Resolution 40, Annex 1, are aircraft observations. These observations are purchased by NOAA and are shared with WMO Member governments immediately. For public safety and security reasons associated with the aircraft, these data are made available to the public only after a 48-hour delay. Data collected by NOAA and Air Force aircraft while conducting reconnaissance for tropical cyclones and winter weather are made available immediately and are covered under WMO Resolution 40. Space weather data are currently not included. Availability of future purchased data will depend on the purchase agreements that are developed.

Pursuant to WMO Resolution 40, Annex 1 subsections (7) and (8),[6] NOAA deems all data from operational geostationary and polar-orbiting satellites as essential. NOAA fully and openly shares its operational geostationary and polar-orbiting satellites data pursuant to both U.S. data policy and WMO Resolution 40, Annex 1 subsections (7) and (8) on an unrestricted basis. NOAA will continue this policy to the extent that NOAA space weather data falls under this policy.

NOAA does not do this alone; it benefits from receiving satellite data in return from WMO Members and partners. NOAA also leverages data from partners around the globe to create a more complete understanding of our dynamic planet, including space weather. In fact, the United States avoids spending billions of dollars to build, launch, and operate satellites by leveraging data from satellites paid for by our international partners. In some cases, NOAA has provided instruments to international partners that resulted in tremendous savings to the taxpayer while providing NOAA with the necessary data to meet its data requirements.

NOAA data activities are governed by the NOAA Policy on Partnerships in the Provision of Environmental Information,[7] NOAA Commercial Space Policy,[8] and the NESDIS Commercial Space Activities Assessment Process.[9] NOAA will continue to explore partnerships with the commercial sector as it maintains its operational capabilities to provide space weather awareness. However, NOAA bases every investment decision on which observing system assets to develop, or data to purchase, and on what is needed in accordance with NOAA and U.S. observation mission requirements.

5. **Is NOAA using the Radio Occultation (RO) data acquired through the Commercial Weather Data Pilot (CWDP) to feed its space weather forecasts? If not, why not?**

**Answer 5:** Radio occultation (RO) data acquired through the CWDP has been shared with the Space Weather Prediction Center to assess whether these commercially sourced data can meet space weather data requirements. Based on CWDP rounds 1 and 2, NOAA is currently pursuing purchase of commercial RO data for operational use in terrestrial models and potentially for space weather forecasts as well.

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[6] (7) "Severe weather warnings and advisories for the protection of life and property targeted upon end-users;" and, (8) "Those data and products from operational meteorological satellites that are agreed between WMO and satellite operators. (These should include data and products necessary for operations regarding severe weather warnings and tropical cyclone warnings)."
[7] https://www.noaa.gov/work-with-us/partnership-policy
[8] https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_217/217-109.html
[9] https://www.nesdis.noaa.gov/sites/default/files/asset/document/nesdis_commercial_space_activities_assessment_process_final%201.6.17%20readable.pdf

6. **Most of NOAA's space weather responsibilities and activities are shared between two Line Offices: the National Weather Service (NWS) and the National Environmental Satellite Data and Information Service (NESDIS). How do the Line Office space weather programs work together?**

**Answer 6:** The National Weather Service (NWS) and the National Environmental Satellite Data and Information Service (NESDIS) work very well together. NWS provides space weather forecasts and warnings, and develops its requirements for space-based data. NESDIS in turn develops the necessary arrangements related to space-based, remotely sensed data to fulfill these requirements. For example, NWS and NESDIS have collaborated on the Satellite Product Analysis and Distribution Enterprise System (SPADES) to provide space weather data from NOAA's geostationary satellites to bolster SWPC monitoring capability.

7. **Multiple agencies support aspects of space weather research, including the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the U.S. Geological Survey (USGS), and the Department of Defense (DOD). How do these agencies coordinate their space weather research efforts? In your view, how effective is that coordination? What could be done to improve it?**

**Answer 7:** In 2018, NOAA, NASA, and NSF signed a Memorandum of Understanding that established a coordinated research effort to support applied space weather research. Funding is administered through the NASA Research Opportunities in Space and Earth Sciences program, and all three agencies contribute to defining the topics for research funding. This represents an initial step to addressing the coordination of space weather research and improving the research-to-operations pipeline. A long-term sustained focus on applied research to support operational needs is needed to address the changing needs of space weather services and supporting research. Additional consideration should be given to support larger scale activities that would enable multi-institution participation in comprehensive numerical prediction model development needed to develop Sun-to-Earth predictive capabilities. All agencies involved in space weather research coordinate basic and applied research through the SWORM Interagency Working Group and through actions identified in the National Space Weather Strategy and Action Plan.

**7a. Are there aspects of space weather research that are not being addressed sufficiently because they fall into gaps between agency programs?**

**Answer 7a:** NOAA and NASA are currently developing a formal framework to incorporate research-to-operations and operations-to-research (R2O2R) contributions from government, industry, and academic partners to ensure there are no gaps between agency programs when it comes to space weather research transitioning into operations. This is further described above in response to Question 5 submitted by Subcommittee on Space and Aeronautics Chairwoman Kendra Horn.

8. **In what ways could Congress facilitate the coordination of space weather activities at NOAA? In what ways could Congress facilitate the coordination of space weather activities across the federal government?**

**Answer 8:** The 2015 and 2019 National Space Weather Strategy and Action Plans have proven to be an effective approach for federal departments and agencies to protect critical infrastructure against space weather storms and coordinate space weather activities across the Federal Government. Enhancing the resilience of critical infrastructure to the adverse effects of space weather on the people, economy, and security of the Nation will necessitate commitment and sustained engagement from government agencies. The National Space Weather Action Plan includes specific program plans for space weather activities across the federal government. Continued prioritization and appropriate funding are key to building national resilience to the effects of space weather.

9. **How could NOAA benefit from the space weather technological capabilities offered by the commercial sector?**

**Answer 9:** The commercial sector plays a key role in the academic-governmental-commercial triad that forms the space weather enterprise. Contributions include risk and threat assessment, data product development, numerical modeling and simulations, data assimilation, small satellite deployment, and development and operation of ground-based and space-based sensors. The commercial sector can and does augment government space weather observation systems.

10. **A 2008 National Academy report stated, "[s]pace weather, a global phenomenon that spans national boundaries, is a challenge best met by international cooperation." The report also described that the space weather landscape in Europe, our most likely international partner, was "complicated" and "very fragmented" and that "European data sources for space weather measurements are fairly limited." What percentage of the world's space weather monitoring and prediction is funded by the U.S.? Should the U.S. taxpayer subsidize other nation's space weather needs?**

**Answer 10:** It is difficult to estimate how much Europe and the rest of the world are funding space weather needs. U.S. global interests in commerce and national security reinforce the necessity for world-wide data to meet U.S. needs. The U.S. requires access to ground stations and space-based measurements from international partners in order to protect U.S. interests. Increased investment from international partners, including Europe, has accelerated space weather forecasting research and expanded the number of space-based and ground-based instruments that are available for U.S. use. While the effective coordination of the growing international effort is still developing, the U.S. benefit from growing international investment in space weather by our partners will continue to increase.

**11. Both the Obama Administration's "National Space Weather Strategy" and the Trump Administration's "National Space Weather Strategy and Action Plan" assigned space weather roles and responsibilities for numerous government agencies. Are specific agencies directed to be the primary agency for specific functions like research, standards development, operations, forecasting, notification, vulnerability assessment, critical infrastructure protection, or mitigation? What are the risks of having multiple different agencies contributing to every aspect of the nation's space weather enterprise? Should specific agencies be directed to lead certain space weather activities within the federal government?**

**Answer 11:** Yes, both the 2015 National Space Weather Strategy and the 2019 National Space Weather Strategy and Action Plan assigned roles and responsibilities to the various federal departments and agencies. In addition, Executive Order 13744 – Coordinating Efforts to Prepare the Nation for Space Weather Events (October 2016), and Executive Order 13865 – Coordinating National Resilience to Electromagnetic Pulses (March 2019) also assign responsibilities to federal departments and agencies. The failure of any agency inhibits our ability to provide warnings for and protect against a space weather event, endangering national and economic security and public safety. The best response to address the risk is to ensure a whole-of-government approach that requires coordinated and sustained commitment across multiple responsible departments and agencies. Joint agency bodies, such as the existing SWORM interagency working group, contribute to government coordination and success.

**12. Multiple agencies support aspects of space weather research, including the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the U.S. Geological Survey (USGS), and the Department of Defense (DOD). How do these agencies coordinate their space weather research efforts? In your view, how effective is that coordination? What could be done to improve it?**
   **a. Are there aspects of space weather research that are not being addressed sufficiently because they fall into gaps between agency programs?**

**Answer 12:** See the answer to question 7 above.

*Responses by Dr. Nicola Fox*

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"*Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities*"

Questions for the Record to:
Dr. Nicola Fox
Director
Heliophysics Division
National Aeronautics and Space Administration

Submitted by Subcommittee on Space and Aeronautics Ranking Member Brian Babin

1. How could NASA benefit from the space weather technological capabilities offered by the commercial sector?

   NASA could greatly benefit from the commercial sector by increased availability of rideshares or hosted payload opportunities. For example, the commercial sector could make available rideshare opportunities in which a research-grade space weather package with a real-time data stream could be flown on most commercial satellites. This would have a profound impact on NASA's ability to provide advanced understanding of space weather.

2. The main focus of the NASA Heliophysics program is fundamental research. How is NASA ensuring that its space weather research is being integrated into other agencies' operational space weather forecasting and mitigation? What could Congress do to help strengthen the connection between research and operations?

   NASA continues to work hand-in-hand with other federal agencies to transition its research to operational environments. Several Memoranda of Understanding (MOUs) between NASA, NOAA, and NSF do exactly this. They include identification of research models that would enable better space weather forecasts and then transitioning those to NOAA for operations. Additionally, NASA Heliophysics missions that have a real-time data stream are made available to NOAA. NASA instrument technology is transitioned for use on NOAA's space weather operational space observatories as needed. Currently, NASA and NOAA are developing a more formalized framework for transitioning research products to operations, the goal of which is make this process effective, efficient, sustainable, and flexible to accommodate of the agencies such as NSF, DoD, and USGS.

3. Small satellites, such as cubesats, are creating new opportunities for flexibility and low cost in a diverse range of space applications. Please describe how the NASA Heliophysics program is currently using small satellites for space weather research. What future opportunities seem most promising for additional use of small satellites? How can cubesats, rideshares, and hosted payloads stretch NASA's heliophysics budget?

NASA is leveraging the commercial sector CubeSat revolution to conduct research relevant to space weather. Most of NASA's CubeSat missions investigate phenomena that are directly related to space weather; for example, the natural disturbances of the ionosphere from the magnetosphere above and terrestrial atmosphere below. This is particularly relevant for space weather impacts on communication, navigation and the Global Positioning System (GPS). NASA is investigating the inclusion of small satellites and CubeSats in future strategic missions such as the Global Dynamic Constellation (GDC) mission, which also has relevance to the space weather impacts on communications and the power grid. Additionally, NASA Heliophysics has a dedicated CubeSat call for research.

4. Astronauts have not left the protection of Earth's magnetosphere since the end of the Apollo program in 1972. NASA's plans to return humans to the Mon, as soon as 2024, make space weather monitoring even more critical for astronaut safety. How do the research efforts of the heliophysics program interface with other NASA programs that are responsible for human space exploration and astronaut safety?
    **a.** To what extent would the accelerated timeline for returning astronauts to the lunar surface require changes in the research priorities for the heliophysics program? How would those changes affect the program's other research priorities?

    All NASA Heliophysics research programs are of great benefit to the space weather initiative and the Artemis program. Currently, we interact with astronaut safety programs, providing models and developing data products to help them forecast and determine all-clear conditions for astronaut extravehicular activities. Additionally, we are coordinating on the Artemis missions, including responding to the accelerated timeline for returning astronauts to the lunar surface. NASA is evaluating the possibility of launching an instrument package on the Gateway that would provide real-time radiation data products for astronaut safety and research opportunities. Furthermore, NASA is assessing the future needs associated with space weather impacts for human missions to Mars and how Heliophysics capabilities can be employed to enhance mission success. This includes space weather models and instruments to enable and enhance space weather forecasting. Human Mars missions will be Earth-independent, and thus will need on-board space weather observation and forecasting capability.

5. A 2008 National Academy report stated, "[s]pace weather, a global phenomenon that spans national boundaries, is a challenge best met by international cooperation." The report also described that the space weather landscape in Europe, our most likely international partner, was "complicated" and "very fragmented" and that "European data sources for space weather measurements are fairly limited." What percentage of the world's space weather monitoring and prediction is funded by the U.S.? Should the U.S. taxpayer subsidize other nation's space weather needs?

NASA Heliophysics is focused on research and does not conduct space weather monitoring or prediction. NASA does collaborate, when it is advantageous to the United States, with international space research agencies to conduct space-based investigations to better understand the coupled Sun-Earth system, and thus space weather. This is proven to be an effective means to get more science for the dollar. Additionally, there are international partners who have developed a few focused space weather models on specific aspects that are better than what we have in the U.S. Therefore, it is advantageous to continue these partnerships so long as they benefit NASA and the U.S. space weather enterprise.

6. Both the Obama Administration's "National Space Weather Strategy" and the Trump Administration's "National Space Weather Strategy and Action Plan" assigned space weather roles and responsibilities for numerous government agencies. Are specific agencies directed to be the primary agency for specific functions like research, standards development, operations, forecasting, notification, vulnerability assessment, critical infrastructure protection, or mitigation? What are the risks of having multiple different agencies contributing to every aspect of the nation's space weather enterprise? Should specific agencies be directed to lead certain space weather activities within the federal government?

    Recent advances in our understanding of space weather and the growing recognition across a broad spectrum of decision makers of the importance of this issue are in no small measure due to strong bipartisan support for the space weather enterprise. Addressing the impacts and mitigation of space weather for the Nation is naturally a multi-agency endeavor. The current "National Space Weather Strategy and Action Plan" identifies lead federal agencies and supporting agencies for the various components and activities of the plan. Agencies have complementary space weather responsibilities and each agency brings unique expertise and capability to the endeavor; we must collaborate to be successful. No one agency has the capability and capacity, let alone the resources, to successfully meet any of the top-level objectives of the National Space Weather Strategy and Action Plan.

7. Given your expertise, are there ground based systems that can improve predictability of space weather events or are there some in the research pipeline? What are they, where are they located and who funds them?

    There are several ground-based observatories and networks that provide critical research data products for space weather research; those include solar observatories, incoherent scatter radars[1], magnetometer and GPS receiver networks, and all-sky imagers. These important ground-based systems are located

[1] The incoherent scatter radar (ISR) technique is a powerful ground-based tool used to measure various properties of the ionized part of the upper atmosphere called the ionosphere. ISRs can be used to measure electron and ion temperatures and velocities, and the number densities of the electrons and the various ions.

across the US and the globe at locations appropriate for the type of observation that is made, e.g., high-altitude mountain tops for optical solar observatories, along particular longitudinal or latitudinal lines for magnetomer chains, and at certain latitudes for radars and all-sky imagers. NASA does not develop or sustain ground-based observatories, although in limited circumstances it has funded ground observations to validate or complement measurements from space missions. NSF and DoD fund several ground-based systems, while others are funded by international agencies.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"*Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities*"

Questions for the Record to:
Dr. Nicola Fox
Director
Heliophysics Division
National Aeronautics and Space Administration

Submitted by Subcommittee on Space and Aeronautics Chairwoman Kendra Horn

1. Many of our Heliophysics spacecraft are beyond, sometimes well beyond, their original prime mission lifetimes. How important are missions like the Solar and Heliophysics Observatory (SOHO, launched in 1995), the Solar Terrestrial Relations Observatory (STEREO, launched in 2006), and others currently operating in extended phase to our space weather capabilities?
    a. What gaps will exist when these missions end, and what would be the scientific impact of those gaps?
    b. To what extent, if any, does NASA consider operational requirements and interests in the planning, design, and development of its Heliophysics missions, in relation to the research and scientific requirements and interests?

   Most of the 19 Heliophysics missions in operation are in extended operations. These missions each are successful in achieving their research goals, and all of them provide data and scientific understanding which are crucial to the space weather initiative, and therefore, are all directly related to space weather. Many of our strategic missions were designed to have the capability to produce real time or tailored products that support the user community in real time, such as STEREO and SDO. They were intentionally developed to support space weather research in addition to their prime science objectives. With the recent establishment of the Heliophysics Space Weather Science Application program, NASA is in the process of assessing and developing a strategy to address the gaps that will inevitably occur. Included in this strategy will be to continue to leverage existing missions in development when appropriate, to accommodate space weather capability, such as real-time beacons or a small space weather package, to secure a focused space weather science mission, to seek share ride opportunities with space weather observations, and to explore concepts of dispersed constellation missions using CubeSats and small satellites.

2. Your prepared testimony highlights NASA's current efforts to work with NOAA to "develop a shared framework for research to operations." What will the shared framework involve?
    a. How are the Space Weather Prediction Center's operational challenges informing the space weather research priorities at NASA?
    b. Are we doing as well as we could be to ensure that there is a robust operations-to-research activity?

c. What types of assessments or reviews does NASA or other partners conduct of the research-to-operations and operations-to-research processes?

The shared framework with NOAA is still in development. It will involve NASA and NSF on the research side and NOAA, DoD, USGS, and others on the operations side. The shared framework will significantly engage the commercial sector and academic community as it is through these communities that the majority of the research and technology innovation is produced. Initially, framework development is focused on establishing the process between NASA and NOAA, as these agencies are the primary funders of space weather research and operations. Once this is accomplished we plan to expand the effort to include other agencies. We see this shared framework as a means to ensure a robust research-to-operations-to research activity. By instilling a process with discipline yet flexibility to accommodate particular aspects of each transition and with validation/verification of the model or technology being transitioned, the expectation is that this will be a significant improvement over previous efforts. Independent assessments of the process will be conducted regularly, especially as agency participation increases. The expectation is that each agency, commercial sector, and academic community will have particular approaches and needs that will require flexibility to be built in the framework.

3. In response to my question on gaps in our space weather forecasting capabilities, Mr. Murtaugh noted that "there are so many unfortunately," that he limited his comments to the Sun, and that he "could share all the way down to Earth with some of the serious challenges we face." Is there a full identification of the gaps in our space weather forecasting capabilities beyond the ones you and Mr. Murtaugh highlighted in response to my question? If so, please provide it for the record. If not, what process do you recommend for identifying the complete set of gaps?

There are known gaps in our understanding of space weather. The current National Space Weather Strategy and Action Plan calls for a bi-annual review by NASA and NSF of the state of space weather research and identification of the top research challenges. An incomplete list of known gaps in understanding includes:

- what drives the active regions on the Sun and how we can predict when one will explode;
- what accelerates the solar wind from the surface of the Sun to the Earth, how we can better predict when it will arrive at Earth, and what its characteristics will be, such as velocity, composition, density, and magnetic field strength and direction;
- what causes some solar storms to have a significant impact at Earth when other, apparently similar, events do not and how we can predict the magnitude of the impact;
- what drives and regulates Earth's radiation belts and how we can predict their state or configuration; and,
- what causes the ionospheric variability that disrupts communication and GPS scintillation and can we predict when it will occur and how intense it will be.

*Responses by Dr. Conrad C. Lautenbacher, Jr.*
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

*" Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities"*

Questions for the Record to:
Dr. Conrad C. Lautenbacher, Jr., VADM USN (ret.)
Chief Executive Officer
GeoOptics, Inc.

Replies for Subcommittee on Space and Aeronautics,
Ranking Member Brian Babin

1. *How important is space weather to national security?*

   A major space weather event has the potential to be cataclysmic and destroy parts of our electrical generation and distribution systems sufficient to cause weeks to months of repairs at apocalyptic costs estimated in the tens of trillions. We can only imagine what would happen to the U.S. without a functioning power grid system.

   It is a matter of probability that one day that the United States could be impacted by a massive coronal ejection on a scale far larger than the Quebec 1989 event. Given that we know that a major space weather event has impacted a section of North America, we must harden and safeguard our electrical generation and distribution facilities, as well as, GPS and other critical technologies, from this very real threat. At top speed -- a solar storm (space weather event) traveling 93 million miles could impact Earth within 18-24 hours. A major space weather event is more than a threat to just national security – it could threaten our way of life and survival.

   Space Weather Data that is observed and collected by satellites operating in the Ionosphere can provide very reliable indications of a more serious space weather event. Possessing data to provide advance warnings can help safeguard GPS and Global Navigational Systems that are of critical life-saving importance to our military installations at home and in overseas deployments.

2. *What are the most important actions Congress and the Executive branch could take to advance the state of space weather research, monitoring, and forecasting over the coming decade. What advances would be enabled by taking those actions?*

   Congress and the Executive branch should support and pass as soon as possible, a Space Weather Bill with actions similar to the latest Weather Bill that both branches have supported and was signed into law in April 2017 (Public Law 115–25, H.R. 353). It is my understanding that the Trump Administration is in the process of updating and adopting the *National Space Weather Strategy and Action Plan* that was developed by OSTP and NOAA officials during the Obama Administration. Congress may want to consider using that report as a legislative template that would provide recommendations to set up government processes to coordinate and direct actions by every agency that would be affected by space weather or would be necessary for recovery from space weather events. The bill would contain inclusion of assets within government agencies, commercial activities, and educational elements of our society. Personnel and joint collaborative actions would need to be documented by position with procedures formulated, annually exercised and sufficiently funded.

3. *Should the federal government design, build, and operate systems to monitor space weather, or simply define the government's data needs and allow industry to propose solutions to meet those requirements? Are data-buys a possibility at this point?*

There will be areas where the federal government should take the lead and others where the private sector will be able to provide the most rapid and cost-effective solutions. However, full and close cooperation between the government and private sector must be in place. Those should be determined by the comprehensive processes put in place in the answer to question 2. recommending close coordination between all available solution providers including government, academic, and private industry.

NESDIS has already provided "its top space weather observational priorities" in the NOAA Space Platform Requirements Working Group (SPRWG) report that was developed in support of the NOAA Satellite Observing System Architecture (NSOSA) study. The study is divided into observational sections: Groups A (Weather and Ocean objectives) and Group B (Space Weather objectives) and Group D (Strategic objectives). https://www.nesdis.noaa.gov/sites/default/files/SPRWG_Final_Report_20180325_Posted.pdf.

Commercial Data Buys can provide essential information (as discussed in the reply to Question #1) and are certainly a possibility. As of today, for example, my company, GeoOptics, Inc is producing worldwide Ionospheric Total Electron Count (TEC) data https://www.swpc.noaa.gov/phenomena/total-electron-content, which is available on a regular basis.

4. *Are there space weather forecasting products that industry can provide that would augment forecasts provided by the government? If so, how do we ensure that government does not undermine those business?*

Yes, the TEC example cited above is one. In addition to data development and provision, the private sector is also skilled in interpreting data and developing innovative solutions more quickly and efficiently than the federal government. The member companies of the *American Commercial Space Weather Association*, http://www.acswa.us/about/members.html are representational of the rapidly increasing activity in space by the private sector and will undoubtedly provide much more in the

future. The commercialization of space is underway and will only increase in the future to provide cutting edge solutions to today's difficult challenges.
One way to help foster greater commercial development is for Congress to develop a broader and increased investment strategy towards Space Weather.

5. *What are the space weather technological capabilities offered by the commercial sector which could benefit the federal government?*

   There is a long list of capabilities which are available today from the private sector of which I have listed a number:

   - Algorithm Development, Automatic event detections (flares, solar energetic particles, geoeffective CMEs)
   - Calibration/Validation
   - Data assimilation
   - GPS modeling and services
   - HF Propagation
   - Numerical modeling & simulation (Sun, Interplanetary medium, magnetosphere, ionosphere, thermosphere, lower atmosphere)
   - Operational implementations/Research to Operations (R2O)
   - Risk and threat analysis for infrastructure and space resources
   - Satellite data analysis & data product development
   - Sensor hardware & modeling
   - Software tools
     - Application development (web-based and smart phone)
     - Data hosting/data product delivery
     - Data/model visualization
   - Space Situational Awareness (SSA)
   - Space Situational Awareness
   - Spacecraft anomaly prediction and assessment
   - Space weather data product and service distribution
   - Space weather now-casting /forecasting

6. *How can the federal government better serve nonfederal organizations that may be interested in space weather forecasting information?*

   Executing the answers to questions 2, 3, and 4. are the first and more important steps. Space Weather planning and operations will benefit greatly from fully incorporating the federal government, private sector and academia into creating an overall national "Space Weather Enterprise" effort, as was achieved for land-based weather in *Fair Weather: Effective Partnerships in Weather and Climate Services* that was developed by the National Research Council/National Academy of Sciences, https://www.nap.edu/catalog/10610/fair-weather-effective-partnership-in-weather-and-climate-services. Understanding and employing the talents and products of each organization will allow the most efficient methods to maximize national success.

Please note that the federal government is not the only organization that possesses forecast development and dissemination skills.

7. *How can the private sector collaborate with federal space weather research, monitoring, and forecasting activities? In your opinion, what kinds of space weather activities should be the federal government's focus and which should be the private sector's?*

   As with question 6, executing the answers to questions 2, 3, and 4 are the first and most important steps to build meaningful collaboration of federal with private sector and academic space weather organizations. Creating a collaborative system within which all can work together by making use of mechanisms that begin with frequent and substantive conversation, and lead to planning and execution optimally employing all segments of the national Space Weather Enterprise.

   The NESDIS SPRWG Report has already defined the federal government's focus on space weather observation (mentioned in Question #3). Under our system the private sector works to support government goals and objectives. However, there may be additional development in space weather research not defined by NASA or NOAA that the private sector or academia is pursuing.

8. *Please identify and describe any policies, working groups, or other mechanisms that help to facilitate space weather public-private partnerships. In what ways can Congress encourage and strengthen public-private partnerships.*

   In general, government rules, regulations, and current laws in force are more suited for working within and across government agency boundaries than they are with private sector companies and other organizations. We must rewrite or augment the current laws which define mechanisms for planning, programming, and budgeting for space weather needs across all potential contributors and create a national organizational structure which makes maximum use of all potential assets. The current government focus for commercial space weather public-private partnerships is the NOAA Office of Space Commerce, but this office is woefully under-funded, https://www.space.commerce.gov/about/mission.

   Congress must provide this office with the financial resources it needs to be mission successful and to develop effective commercial partnerships. Next there needs to be specific funding mechanisms that allow for easier incorporation of private and academic organizations to obtain funding and government support.

   Congress can provide increased assistance to many of the small companies that conduct Helio-based research. Plus consider creating a Commercial Space Weather Data Buy Program to contract with companies like GeoOptics for them to provide their to space weather data to advance federal agencies knowledge of potential space weather events.

9. *Should the U.S. taxpayer subsidize industries that rely on space weather data or should the government step away and let the free market deliver sector solutions to the private sector's space weather needs.*

   The federal government had always been a world leader in funding cutting edge basic research for all disciplines and as a result, has made our nation great. That process should be installed for Space Weather needs as well. This is not an either/or situation between government and the private sector. Government research funding is the foundation of a strong future. The results will be used by all sectors of the economy and all sectors should be considered and treated as important producers as well as critical users of data, innovator concepts and hardware. A fully integrated approach is vital to our success in meeting space weather challenges.

10. *How will Radio Occultation (RO) data help with producing better and more accurate space weather forecasts? How is RO a space weather measurement? How are these data different from the data different from the data collected through the Commercial Weather Data Pilot for land weather? What will increased investments in RO data buys net for the American public?*

    RO data is the only data, satellite or ground based, that produces accurate vertical readings of pressure, temperature, and moisture in meters! It is at the top of the value list of data needed to provide accurate weather models. Research shows that the more RO data we can produce, the better the accuracy and warning times produced by weather models.

    RO data is also extremely valuable to Space Weather forecasting by providing the Total Electron Count (TEC) of charged particles in the ionosphere (which is about the troposphere -- the part of the atmosphere that produces our weather). The same types of mathematics that provide weather data in the troposphere also can provide TEC in the Ionosphere!

    The net for the American public is significantly increased warning times for life threatening weather events, and the saving of additional lives, as well as better understanding of ionospheric disturbances which can interfere and or block critical worldwide communications. The satellites are the size of a shoe box and at least several orders of magnitude less expensive than the large heavy weight satellites we have been using for decades.

Replies for Subcommittee on Space and Aeronautics,
Chairwoman Kendra Horn

1. *What capabilities and infrastructure are currently available in the private sector to collect relevant data or model and predict space weather events?*
   a. *How have advances in technology, such as miniaturization and CubeSats, changed the kinds of data the private sector can collect or the way the private sector can collect these data?*

The private sector is now manufacturing and fielding nanosats which produce data that provide Total Electron Count (TEC), https://www.swpc.noaa.gov/phenomena/total-electron-content essential to forecasts of the viability of the communications that underpin worldwide commerce, national security and public safety.

The miniaturization and technical improvements that revolutionized the commercial private sector are available now at two orders of magnitude less expensive than currently employed large scale, one of a kind, satellites. Efficiencies pioneered by the commercial sector will significantly lower the costs and revolutionize forecast accuracy of both tropospheric weather and worldwide ionospheric communications.

*Responses by Dr. Harlan E. Spence*

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

*"Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities"*

Questions for the Record to:
Harlan E. Spence, Ph.D.
Director, Institute for the Study of Earth, Oceans, & Space and Professor of Physics and Astronomy
University of New Hampshire

Submitted by Chairwoman Eddie Bernice Johnson

1. You have worked closely with NASA on several missions, including the Lunar Reconnaissance Orbiter and the Van Allen Probes. Please characterize your interactions with NASA and any other federal agencies involved.
    a. How effective was your collaboration? How did working with NASA facilitate your own research and improve the state of knowledge of space weather more broadly?

***My mission involvements with NASA have been nearly exclusively through the Science Mission Directorate (SMD). My collaborations with SMD have been uniformly excellent. These interactions work well when agencies and academia work together as a team. For the most part, I would say that both sides of the partnership have learned over experience how to work together, though each agency and each academic institution have different norms, business practices, and cultures. Mission management is somewhat formulaic, is established around a set of policies and practices, and with clear swimming lanes and roles and responsibilities.***

***A single principal investigator at a single university, or even a collection of principal investigators at multiple universities would be challenged to manage a large complex mission like LRO or Van Allen Probes without an implementing field center. NASA works effectively with the academic science community (as well as other non-NASA members of the community) to enable missions. In many cases, they facilitate the coordination across and between instruments, develop the spacecraft, and implement mission operations. NASA has the expertise and continuity needed to excel at these functions. That allows the university community (and other communities) to develop mission science goals, mission architecture, and instruments needed to meet those goals.***

***In my case, LRO provided a mission that enabled my team to design, build, and operate a novel radiation sensor that has now operated over a solar cycle in lunar orbit. That sensor is directly enabling safe human return to the Moon by quantifying the radiation environment near the Moon. It is also allowing us to discover other forms of space radiation not measured by previous missions, by conducting basic research of how galactic cosmic rays striking the lunar surface produce an albedo of charged particles created in the lunar regolith. Without this opportunity, such a partnership between academic institutions and NASA would not have happened. And it is an effective one that has advanced not just basic science but is also enabling safe human exploration.***

b. What is the current infrastructure for space weather information and data sharing between federal agencies such as NASA, and academia? How well does the public sector respond to and incorporate relevant academic research?

***NASA has been a leader in assuring that mission data be made available publicly as soon as feasible. The transformation in data sharing since the time I was a graduate student and now is remarkable. Whereas thirty years ago, much data remained in the purview of individual investigators, now essentially all mission data is openly available in useable form as soon as possible. NASA policy enforces that outcome, and it is to the benefit of all. By providing wider access of these data, the broadest community is able to analyze and advance the science, including the science of space weather.***

***While data sharing capability has been transformational over the past 30 years, I would assert that we have not enjoyed the same degree of connections between research at academic institutions and the public sector. Though that outcome has been the focus of more recent attention, it requires a different sort of engagement, and funding to enable that engagement. Funding to support such efforts has been comparatively low in the past. And in the academic setting, basic research is generally valued more than operational efforts. These two main factors limit how effectively information gleaned from basic research is translated to operation.***

c. What, in your view, is the role of academia in the space weather field? How can Congress best support this work?

***I believe that academia has several roles to play in the space weather field. Congress can help by supporting these roles legislatively and through authorization and appropriation. One role is in the generation of new roles through basic research that encompasses data analysis, numeric modeling, and theory .The science of space weather will only advance if we continue to improve our observations, use those observations to guide the development of improved models, and develop and test the theories that undergird space weather prediction.***

***A second role is through the development of human capital, namely training the next generation of space scientist. It is clear that space weather research will require a next generation and academia is the fount of the new scientists and engineers who will advance the field. While an obvious thing, we must always value this training element. Without academia and the generation of new scientists and engineers (let alone new ideas0, the future of the space weather enterprise would be perilous.***

2. The Van Allen mission, which you participated in as the principal investigator of several particle instruments onboard, recently ended. What are the major achievements with regard to space weather observations of that mission, and what major research gaps are left or have been identified by the probes?

**The Van Allen Probes mission has rewritten the textbook of radiation belt physics. Before the mission we knew that the textbook needed rewriting, however we did not have the observations needed for that new version. This mission allowed us to identify and quantify the physical processes responsible for accelerating charged radiation belt particles to high energy, as well as to causing those particles to be lost from the system. The mission has done this as well as discovering when and where and how these competing processes battle in the tug of war to control the spatial distr.bution and temoporal evolution of the belts. Before the mission, we did not have sufficient knowledge to develop more than conceptual models of belt dynamics. As the mission concludes, we now have much greater quantitative knowledge that allows dramatically improved forecast capability.**

**The Van Allen Probes has indeed ceases operations and the mission is now in the final data archival stage. As a basic science mission, one can claim mission success because major science questions have been answered. Nevertheless, as the mission concludes, we now lack many of the key measurements needed to drive the models. While progress can be made by using low altitude observations together with substantial geostationary observations, the bulk of the radiation belts will remain unobserved in the post-Van Allen Probes era. To leverage the Van Allen Probes mission, we thus need a more operationalized version of the basic science mission in order to convert that basic science to operations.**

3. We know that space weather events can damage a range of important infrastructure, such as electrical grids, navigation systems, radio communication, and even voting systems. From your perspective, how prepared are we to deal with a major space weather event?
    a. How well does academic research aid in operationalizing tools and strategies to prevent loss of communications, satellite signal disruptions, electrical transmission issues, and more, into defenses adopted by the public sector?

**I believe that we are ill prepared as a Nation against a major space weather event, and certainly not an extreme one. Though perhaps statistically unlikely, a major space weather event has the capacity to create wide spread chaos and with national security concerns. So even though rare, the consequences are enormous and deeply concerning.**

**There is a growing sense of urgency within the academic research community in quantifying space weather extremes and then sharing that information or even working hand-in-hand with the public sector. However, funding to support research to operations has not been a priority of science-focused activities within NASA SMD and the NSF. Operationalizing a model is not simple or straightforward. Though many in the community are eager to advance these issues, agency fuding to support is often scant.**

<u>Initial Questions for Consideration with Answers – Harlan Spence</u>

1. NASA and NSF are both developing missions and facilities and supporting research that endeavor to understand fundamental phenomena that are directly relevant to space weather. Operational agencies like NOAA are likewise working to improve our space weather monitoring and forecasting capabilities. While these activities certainly signify progress, it's clear that our space weather prediction and mitigation regime is not where it needs to be. **What are the critical research gaps that still need to be filled if we are to advance our prediction capabilities? Furthermore, what do you see as the main obstacles preventing us from more rapidly integrating new research advancements into the operational space? How can we improve?**

*To improve prediction capabilities, we must first recognize that each customer of space weather prediction may have different needs. In that way, there may be many gaps which are needed to bridge from a general prediction of space weather phenomena and the specific effect which may affect a particular customer. This is very much an issue of research to operations. While we might make an advance in predicting the physics of a space weather event in the coupled Sun-Earth system, that alone is not necessarily sufficient. We must also go the next steps in bringing that space weather effect directly to a customer need. For example, we have developed better predictive models of how coronal mass ejections are spawned at the Sun, how the propagate and evolve through interplanetary space, how they interaction with Earth's magnetosphere, how that interaction produces global geomagnetic storms, and how the effects of those geomagnetic storms produce electric currents in the Earth's ionosphere which can lead to geomagnetically induced currents (GICs). However, that alone is not sufficient. While such predictive models provide for improved alerts, a more fully operational model must predict how GICs at a local scale will couple into an affect the operations of a specific local or regional power grid.*

*To move from our current predictive capability to one that is more advanced requires that we identify the key missing observations, physical mechanisms, and coupling parameters that are needed not merely for developing a physics-based model, but also for making validated and verified predictions for given systems at specific locations. In the context of GICs, for example, details of the local electrical conductivity of the Earth is required, which in part requires knowledge of soil moisture. In cases like this, the problem is deeply interdisciplinary. This requires a deep connection between interdisciplinary research teams and the operations community. Venues like Space Weather Week provide an annual forum for industry and the research community to come together to identify the missing areas and strategic partnerships. However, funding specifically for identifying and bridging these gaps is only recently available. That funding cannot come at the expense of the basic research; in exploring these gap "spaces" we will invariably face new challenges that require basic research to advance predictability. Additional funding and opportunities from agencies are needed to foster research-to-operations partnerships. I believe that the research community is eager to help in this regard, however, present relatively low funding amounts limits our ability to more rapidly integrate new research advancement into operational space.*

2. Agencies like NASA, NSF, NOAA, and DOD use a variety of space-based and ground-based capabilities to study and monitor space weather and other related phenomena. **From your perspective, why is it important that we maintain a diverse suite of platforms for observing space weather? Can you provide examples of how these platforms work in concert with one another?**

*Diverse observing platforms provides several advantages. First, some types of observations provide immediate situational awareness or specific measurements needed to drive a predictive model. Such platforms thus provide primarily a monitoring capability and with instrumentation that is tailored for that purpose. Those sorts of platforms often have very different observational and operational requirements than those dedicated to exploring a basic science question. Such research-focused platforms are developed so that their unique measurement capabilities are designed to reach closure on an important science question (indeed ones that may have significant space weather predictability implications). In some cases, there may be platforms that can have dual use (research and operations), though in practice, to improve our capabilities, we will need ongoing missions that are a balance of those which primarily monitor (NOAA and DOD) and of those that primarily conduct basic research (NASA and NSF).*

*A diversity of observing platforms is also needed simply because space weather operates over such vast realms and involves so many different connected systems and processes. In many ways for space weather predictability, we have made advances as much through analyzing measurements from multiple missions operating at the same time as we have from analyzing only individual missions. Whereas a single mission is usually focused on a single region or even process, analyzing a space weather event from a multitude of simultaneously operating missions allows one to see how the system of systems behaves. NASA's Heliophysics System Observatory (HSO) underscores this point. Without the diversity of HSO platforms observing different parts of the system simultaneously, we would be hard pressed to unravel all the ways by which energy flows through the system, a key to unlocking the effects of that energy flow on ground- and space-based technologies.*

*A diversity of platforms is also warranted for very practical reasons. Some basic research or monitoring capabilities have requirements that mandate, for example, substantial spacecraft resources. To accomplish a science mission or provide necessary monitoring might require a mission mass of metric tons and high costs. On the other hand, some missions needed to answer a question or provide a key measurement for a model may have more modest requirements, and hence a more modest implementation and cost. Whereas the largest missions require high oversight and long mission development, missions of smaller scope can be done with less oversight and shorter life cycles. Finally, some missions are inherently exploratory or provide a narrow but important opportunity for a new measurement. At one extreme, CubeSats provide an example of such missions that are very low cost, higher risks, and very rapid turn-around. To advance space weather, we require a balanced program that incorporates missions of all sizes and scopes.*

*Finally, it is important to note that when that ecosystem of mission size and scope is devised thoughtfully and synergistically, then results amplify. For example, the Van Allen Probes is an example of large NASA mission with comprehensive science goals. In the context of radiation belt science, NASA also selected an intermediate cost balloon program called BARREL, which operated contemporaneously with Van Allen Probes. Whereas Van Allen Probes measured the radiation belt particles at high altitudes in the magnetosphere, that mission alone could not see how those particles interacted with the atmosphere;*

*BARREL provided an indirect measure of that interaction by measuring x-ray emissions on a series of balloons. Finally, the very low cost NSF-funded FIREBIRD-II CubeSat mission, measured details of the radiation belt particles as they entered the atmosphere. Together, the research community took advantage of mission opportunities spanning small to large in a way that provided tremendous outcomes that could not be done with simply the largest mission. That diversity of opportunity resulted in tremendous scientific return on investment from tax payer support.*

3. As you've outlined in your written testimony, basic science missions like the Van Allen Probes and MMS can significantly expand our understanding of the fundamental mechanisms underpinning space weather while simultaneously contributing unique attributes to our observational architecture. As critical as these missions are, they ultimately can't operate indefinitely and losing one unexpectedly could severely impair our monitoring and forecasting capability. **How do you view the role of emerging technologies like CubeSats and SmallSats in rapidly filling observational gaps? Can we be doing more to leverage these sorts of platforms?**

*As noted above, SmallSats (including CubeSats) are no longer engineering "stunts." These missions are increasingly sophisticated and naturally balance mission risk with return on investment. In addition, of course, this class of mission has proven successful for academic institutions in training the next generations of space scientists and aerospace engineers; these smaller missions with short life cycle and risk tolerance are ideal as a proving ground for new ideas and new human capital. Along with other low-cost access to space opportunities for students, SmallSats provide new opportunities for orbital measurements. As New Space continues to expand, industry looks increasingly to students with real-world experience. We should provide more opportunities to leverage these programs for the benefit of the government and industry.*

*Because of their low cost and short development cycles, small missions also can be incredibly responsive to a critical need, whether it is to address a research opportunity or to address a space weather operational issue. While we have made great advances with such small missions, it is important that these programs continue to have appropriate risk postures, lest they lose their value in the diverse ecosystem described above. Certainly, not all needs can be met within a smallsat envelope, so we will always need a balance program that includes large, intermediate, and small opportunites. However, because they are so low cost compared to the cumulative costs of large and intermediate missions, I believe that we can enhance our national smallsat platform investments, without a major impact on the larger missions. Indeed, as noted above, when the smallsats are integrated into large missions in a deliberate and thoughtful manner, everyone benefits. We should continue to develop programs that look for such synergies to more rapidly advance space weather observational capabilities.*